RAW PHOSPHATE ROCK AS A FERTILIZER

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BULLETIN

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RAW PHOSPHATE ROCK AS A FERTILIZER

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The increasing price of acid phosphate, due to the consumption of sulphuric acid in the European War, is causing a renewed inquiry respecting the possibility of substituting finely ground, untreated phosphate rock for that which has been treated with sulphuric acid.

This problem has been under investigation for many years, but the results have been contradictory. It has seemed worth while, therefore, to compare some of the principal experiments, in order, if possible, to learn the causes of the difference in their outcome.

PENNSYLVANIA EXPERIMENTS

In 1884 the Pennsylvania State College began an experiment in which raw phosphate rock, obtained from South Carolina, was compared, not with the same rock treated with sulphuric acid, but with "dissolved boneblack," which was then the more common carrier of available phosphorus, and which was made by treatment of boneblack which had been employed for other purposes (the refining of sugar, oil, etc.) with sulphuric acid.[1]

At that time there was considerable interest in the availability of phosphorus that has been made soluble in water by treatment with sulphuric acid and then has "reverted" by combination with lime to a form soluble only in weak acids. In order to obtain light on this question a part of the dissolved boneblack was mixed with lime a short time before application to the land.

The experiment was located on the soil of the State College farm, a soil formed by the decomposition of limestones, which lie so near the surface as to give natural underdrainage. Twelve plots, of one-twentieth acre each, were given to the work, which was carried through three 4-year rotations of (1) wheat, (2) clover and

[1]Penna. State Coll. An. Rpt. (1895) pp 157-210.

timothy, (3) corn and (4) oats, from 1884 to 1895, inclusive, thus growing each crop three times. Table I gives the quantities of fertilizing materials applied, and Table II, the 3-year average yields of the crops grown during the experiment, together with the total value of the four crops of each rotation.

TABLE I.—Pennsylvania experiment with carriers of phosphorus. Fertilizers applied per acre

Plots	Fertilizer	Quantity per acre	Essential constituents per acre		
			Nitrogen	Phosphoric acid	Potash
		Lb.	*Lb.*	*Lb.*	*Lb.*
A & G	Dissolved boneblack Muriate of potash Sulphate of ammonia	200 200 240	47	32	100
B & H	Dissolved boneblack* Muriate of potash Sulphate of ammonia	200 200 240	47	32	100
C & I	Raw bonemeal Muriate of potash Sulphate of ammonia	150 200 240	51	40	100
D & J	South Carolina rock Muriate of potash Sulphate of ammonia	150 200 240	47	40	100
E & K	Muriate of potash Sulphate of ammonia	200 240	47	....	100
F & L	Nothing	....	....	....	....

*With an equal weight of lime.

The fertilizers were applied to both wheat and corn, being sown broadcast and harrowed in after the land was plowed. The quantity for each rotation, therefore, was double that shown in the table.

Table II shows that in the average of the three wheat crops the yields of Plots A and B fell 5½ and 2¼ bushels, respectively, below those of E, and the yields of oats on A likewise failed by nearly 5 bushels to attain the yields given on E. The yields of hay and corn, however, were considerably greater on A and B than on E. It is evident, therefore, that the inequalities in the soil of Plots A and B were so great as to render the results obtained on those plots not only worthless but misleading. The omission of an unfertilized check plot, preceding Plot A, was a fatal defect in the plan of the experiment. At the time when this experiment was planned, however, the science of field experimentation was in its infancy; the Rothamsted experiments were then practically the only guide in such work, and Broadbalk Field, at Rothamsted, has only two check plots in its total of 20 plots.

TABLE II.—Pennsylvania experiment with carriers of phosphorus. 3-year average yield per acre of crops grown in 4-year rotation, 1884 to 1895, inclusive

Plot	Treatment	Wheat 1884-88-92		Hay 1885-89-93	Corn 1886-90-94		Oats 1887-91-95		Value of four crops of rotation*
		Grain	Straw		Grain	Stover	Grain	Straw	
		Bu.	*Lb.*	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*	*Doll.*
A	Dissolved boneblack	25.14	2,907	3,400	50.38	2,147	41.39	1,362	83.57
B	Boneblack and lime	28.55	3,087	3,500	51.94	1,973	49.06	1,423	90.11
C	Raw bonemeal	30.95	3,243	3,480	54.90	2,213	51.48	1,723	95.06
D	Raw Carolina rock	32.59	3,443	3,200	49.43	2,017	49.97	1,628	91.64
E	No phosphorus	30.78	2,687	2,450	43.24	1,667	46.31	1,136	80.18
F	Nothing	21.06	1,703	1,833	34.10	967	40.99	1,055	60.84
G	Dissolved boneblack	31.31	3,122	2,933	47.33	1,767	46.12	1,311	85.88
H	Boneblack and lime	31.25	3,328	3,100	47.27	1,900	45.13	1,229	86.65
I	Raw bonemeal	32.21	3,433	3,250	49.02	1,933	47.30	1,467	90.20
J	Raw Carolina rock	30.53	3,233	3,067	45.85	1,800	46.49	1,486	85.71
K	No phosphorus	30.40	2,910	2,533	38.13	1,667	44.76	1,298	77.71
L	Nothing	23.97	2,228	2,263	32.02	1,089	36.61	1,135	63.78

*Computing wheat at 80 cents per bushel; corn at 50 cents; oats at 32 cents; hay at $10 per ton and stover and straw at $2.50 per ton.

The average yields of wheat, hay and oats on Plots E and K, receiving nitrogen and potassium without phosphorus, have been sufficiently uniform for comparison. The corn yields have been less regular, but it seems legitimate to compare the yields of Plots C to J, inclusive, with the average yields of Plots E and K. Such a comparison is given in Table III, which shows the average increase due to the nitrogen and potassium applied to Plots E and K, together with the further increases following the addition of the different phosphates to this treatment, as found by subtracting the average yields of Plots E and K from those of C and I, D and J, and G and H, the yields on these last-named plots being so nearly identical that it is evident that the reversion of the phosphorus has not affected the yield.

TABLE III.—Pennsylvania experiment with carriers of phosphorus. Average increase per acre from fertilizers, with its value

Crop	Increase for nitrogen and potassium		Additional increase for phosphorus in: Raw bonemeal		Raw S. C. rock		Dissolved boneblack	
	Grain	Stover, straw or hay†	Grain	Stover, straw or hay	Grain	Stover, straw or hay	Grain	Stover, straw or hay
	Bu.	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*
Corn	7.62	643	11.28	406	6.96	241	6.62	166
Oats	6.73	122	3.86	378	2.70	340	.09	53
Wheat	8.07	833	.99	540	.97	540	.69	427
Hay	....	443	....	874	....	642	....	525
Annual value of increase*	$4.16		$3.36		$2.43		$1.90	
Annual cost of fertilizers	7.20		1.05		.50		.80	
Annual net gain or loss (—)	— 3.04		2.31		1.93		1.10	

*Computing corn at 50 cents a bushel; oats at 32 cents; wheat at 80 cents; stover and straw at $2.50 a ton and hay at $10 a ton.

†Computing nitrogen at 20 cents a pound in sulphate of ammonia and 12½ cents in raw bonemeal; potash at 5 cents in the muriate, and phosphoric acid at 5 cents in dissolved boneblack, 4 cents in bonemeal and 2¼ cents in raw Carolina rock, cost of application included.

It will be observed that the increase from raw phosphate costing 50 cents has been $2.43, or at the rate of $4.86 for one dollar invested in the fertilizer, whereas the gain from bonemeal has been but $3.30 for one dollar invested. If it were shown that doubling the rate of application of the raw phosphate would double the rate of increase, the conclusion that the raw phosphate was the cheaper fertilizer would be justified; but there is not sufficient evidence that such a result would follow the increase of the phosphates.

On the contrary, all experience has shown that as the quantity of fertilizer is increased the gain per unit of fertilizer diminishes until a point is reached beyond which there is no further gain, but may even be a loss. For example, in the Pennsylvania experiments described farther on 48 pounds of nitrogen, costing $9.60, has added $7.49 to the total increase of the four crops of the rotation, as a 30-year average; 96 pounds of nitrogen, costing $19.20, has added $10.28 to the increase; and 144 pounds of nitrogen, costing $28.80, has added $11.37 to the increase. In the Ohio experiments at Wooster 76 pounds of nitrogen, costing $15.20, has added $14.59 to the value of the increase, and 114 pounds of nitrogen, costing $22.80, has added $15.29 to the increase, as a 20-year average, the nitrogen being given in both experiments in nitrate of soda and rated at 20 cents per pound of nitrogen.

This question is illustrated in another way by the Ohio experiments. In the 5-year rotation at Wooster one fertilizer, costing 50 cents per acre annually, has produced a 20-year average annual increase worth $3.30 per acre, or $6.60 for each dollar invested in fertilizers. During the same period and under the same conditions of soil, cropping and cultivation, another fertilizer, costing $3.50 per acre annually, has produced increase having an annual value of $7 per acre, or only $2 for one dollar's worth of fertilizers. Thus, while the gain from one dollar invested has been more than three times as great in the first case as in the second, the *net gain per acre* has been 25 percent greater in the second case than in the first. It is the net gain per acre which is the matter of importance, not the percentage gain on the dollar invested, so long as the gain is sufficient to pay more than the usual rate of interest on the investment.

The fallacy of considering only the percentage gain on the money invested in calculating the profits from the use of fertilizers lies also in part in the fact that the cost of the fertilizer is only one factor in the cost of crop production. Rental or interest on the investment, seed and labor must also be considered, and these combined constitute the larger part of the cost.

It does not follow, therefore, that if one dollar expended in the first treatment would produce $7 worth of increase on two acres, this treatment would be cheaper than to spend $3.50 to get the same increase on one acre. The rental value of the land alone would more than offset the difference in cost of fertilizing, to say nothing of the extra seed and the greater labor cost of traveling over two acres to cultivate and harvest the crop that might be grown on one.

Table III shows that there was a considerable increase from the application of nitrogen and potassium, although but little more than half enough to pay for the fertilizers, on the scale of prices here employed.

In order to bring out fully the effect of the phosphates it was necessary that nitrogen and potassium should be used liberally; hence the fact that the cost of these elements has not been recovered in the increase of crop does not affect the object of the experiment, which was to compare the different phosphate carriers. The outcome shows the largest total and net increase from the bonemeal, with the raw rock phosphate second and the dissolved boneblack last. As compared with other tests, this experiment shows relatively high values for nitrogen and potash and a low value for phosphorus.

Parallel with this test, the Pennsylvania Station has conducted another experiment in which the same crops are grown in the same rotation, which in this case is so arranged that each crop is grown every season. This experiment was begun in 1882, or 2 years earlier than the phosphate test, and is still in progress. In this test also the fertilizers have been applied to the corn and wheat, leaving the oats and clover untreated. Phosphorus, however, has been applied in one-half larger quantity—48 pounds of phosphoric acid per acre for each application, instead of 32—and carried only in dissolved boneblack. Potassium has been used in the same quantity and same carrier—200 pounds of muriate of potash at each application—in both tests. Nitrogen has been used in the three carriers, dried blood, nitrate of soda and sulphate of ammonia, and in the three quantities of 24 pounds, 48 pounds and 72 pounds of nitrogen at each application, except that, where nitrogen and potassium are used in the absence of phosphorus, the quantity of nitrogen has been 24 pounds only, and the carrier, dried blood. With the scale of prices given under Table II, which are those employed by the Pennsylvania Station, the financial outcome of certain parts of this test is shown in Table IV by six successive 5-year periods.

In comparing Table IV with Table III it must be borne in mind that phosphorus has been used in larger quantity in the experiment reported in Table IV than in the one shown in Table III, and that nitrogen has been used not only in smaller quantity but in dried blood instead of sulphate of ammonia, this comparison being necessary because sulphate of ammonia has been used only in the complete fertilizer in this test. Where dried blood and sulphate of ammonia were used under like conditions and in equal quantities of nitrogen, the sulphate of ammonia produced the larger effect during the earlier years of the work, but after the first 15 years it began to show a toxic effect when used to contain 48 pounds of nitrogen or more, and the dried blood passed it in yield.

TABLE IV.—Pennsylvania experiments on crops grown in rotation for 30 years. Annual value of increase per acre from fertilizers

Period	Phosphorus alone	Nitrogen* and potassium	Phosphorus, potassium and nitrogen* over potassium and nitrogen
1st 5 years	$0.15	—$0.13	$2.59
2d 5 years	1.05	.60	2.49
3d 5 years	2.82	— .33	6.97
4th 5 years	3.16	.66	6.52
5th 5 years	4.10	.81	7.43
6th 5 years	4.20	1.11	8.41
30-year average	2.53	0.45	5.74

*Nitrogen 24 pounds in dried blood.

The point of special importance in Table IV is the relatively small effect of phosphorus during the earlier years of the test as compared with that obtained later. It would seem, therefore, that the phosphate test described in Tables II and III was discontinued before the full effect of the phosphates had been realized.

In this 30-year test two plots have received their phosphorus in bonemeal, given to carry the same quantity of phosphorus as that applied in the other treatments, and with the standard application of 24 pounds of nitrogen in dried blood and 100 pounds of potash in the muriate, thus raising the total nitrogen application to 30 pounds. The 30-year average annual value per acre of the increase from this treatment over that produced by nitrogen and potassium alone, is shown below:

Treatment	Value of annual increase for phosphorus
24 lb. nitrogen in dried blood 48 lb. phosphoric acid in dissolved boneblack	$5.74
48 lb. nitrogen in dried blood 48 lb. phosphoric acid in dissolved boneblack	7.29
24 lb. nitrogen in dried blood 6 lb. nitrogen in bonemeal 48 lb. phosphoric acid in bonemeal	7.39

This outcome indicates that a part of the superiority shown by bonemeal must be ascribed to the nitrogen it carries.

The total quantity of phosphoric acid applied in raw phosphate in the special phosphate test was 80 pounds per acre for each 4-year period, carrying 35 pounds of phosphorus, while the increase of crop contained not more than about 3½ pounds of phosphorus, or 10 percent of that given in the fertilizer.

The experiments which will be described farther on show that a part of the phosphorus carried in finely ground raw phosphate rock is immediately available and the proportion so available has been estimated at about 3 percent of the gross weight of the ground rock by a producer who furnished this material to the Ohio Experiment Station some years ago.

So long, therefore, as each of the phosphates furnishes sufficient available phosphorus to meet the demands of the crop under existing soil conditions no marked differences in their effectiveness can be expected. It is not until the soil conditions become such that the crop demands a much larger quantity of phosphorus than the soil can supply that differences in availability can be detected, and even then the quantity of phosphorus supplied in the fertilizer must be kept well within the limits of possible utilization if comparative results are to be attained.

ALABAMA EXPERIMENTS

In Bulletin 22 of the Alabama Experiment Station an experiment is reported in which 400 pounds of floats and 400 pounds of acid phosphate, each mixed with 400 pounds of cottonseed meal, were used on "a sandy drift that had been lying out for many years" in the production of cotton. No commercial fertilizer had been previously applied to this land, and it had been closely depastured for 7 years. The outcome was a net gain over the cost of the fertilizers of 69 percent for the floats and 62 percent for the acid phosphate. This result is said to be in harmony with previous experience.

MAINE EXPERIMENTS

During the 9 years, 1886 to 1894, the Maine Experiment Station conducted an experiment in which acidulated phosphates, ground bone and ground raw South Carolina rock were used in connection with sulphate of ammonia and muriate of potash in complete fertilizers. The acidulated phosphate consisted of 400 pounds per acre of dissolved boneblack for the years 1886 to 1889, inclusive, after which 500 pounds per acre of acid phosphate was used. The South Carolina rock was used at the rate of 300 pounds per acre. Sulphate of ammonia or nitrate of soda was used at the rate of 200 pounds per acre with acidulated phosphate and raw phosphate, and of 140 pounds per acre with bonemeal, and muriate of potash was used at the rate of 100 pounds per acre. The cropping is shown in Table V.

TABLE V.—Maine experiment with carriers of phosphorus

Year	Crops and treatment	Fertilizers and yield per acre (pounds)				
		None	Acid phosphate	Bonemeal	S. C. rock	No phosphate
1886	Oats, fertilized	3,664	5,900	5,420	5,052	4,500
1887	Oats, fertilized	2,000	3,400	2,566	3,100	2,700
1888	Hay, not fertilized	1,566	2,434	2,800	2,566	2,234
1889	Fallow, fertilized	....	....	....	....	....
1890	Peas, not fertilized	1,406	1,850	1,922	1,762	1,422
1891	Oats, not fertilized	1,892	2,332	2,466	1,936	2,000
1892	Peas, not fertilized	1,216	1,124	1,072	860	1,180
1893	Corn, fertilized	395	1,415	1,326	1,076	905
1894	Corn, fertilized	749	2,926	3,038	2,631	1,879
	Annual increase	....	916	824	617	346
	Annual increase for phosphorus	....	570	474	271	....

The average annual increase in total crop produced by the phosphates, in excess of the yield of the land receiving the same quantities of nitrogen and potassium, in the same carriers, but no phosphorus, is shown below:

Treatment	Annual increase per acre *Pounds*
Acidulated phosphate	570
Bonemeal	474
Raw phosphate	271

In 1888 the Maine Station began another experiment in which, after two crops of hay were harvested in order to test the uniformity of the soil, acidulated phosphate and raw rock phosphate were applied in 1890 to two tracts of land of 2½ acres each and crops were grown for 5 years without any further treatment. In this test the phosphates were applied at the rate of 1,000 pounds per acre of South Carolina rock and 500 pounds of acid phosphate, accompanied by nitrate of soda and sulphate of ammonia carrying 14 pounds of nitrogen, and muriate of potash carrying 50 pounds of potash, only one application being made for the 5-year period. A summary of this test is shown in Table VI:

TABLE VI.—Maine experiment with carriers of phosphorus

Cropping	Yield per acre			
	Plot 1 Barn manure	Plot 2 Raw phosphate	Plot 3 Acidulated phosphate	Plot 4 Nothing
	Lb.	*Lb.*	*Lb.*	*Lb.*
Hay, average 1888 and 1889	2,542	2,416	2,082	2,510
Barley and peas, 1890 (fertilized)	2,208	1,712	1,422	1,118
Oats, 1891	3,818	2,981	2,972	2,480
Barley hay, 1892	3,444	2,324	1,930	1,161
Fallow, 1893	....	....	....	....
Oats, 1894	1,894	2,453	1,734	957
Average yield of 4 crops	2,841	2,367	2,014	1,428

From a comparison of the yields of the four fertilized crops with those of the two preceding hay crops it would seem that 1,000 pounds of raw phosphate has produced about the same effect as 500 pounds of acid phosphate.

MASSACHUSETTS EXPERIMENTS

In 1890 the Massachusetts Experiment Station[1] undertook a comparison of various carriers of phosphorus, in which equal values of the different phosphates, at the then current market rates, were employed. The actual amounts of phosphorus, calculated as phosphoric acid, applied to the different plots per acre were as shown below:

Plot	Carrier of phosphorus	Phosphoric acid
1	Phosphatic slag	96.72
2	Mona Guano	72.04
3	Raw Florida rock phosphate	165.70
4	Raw South Carolina rock phosphate	144.48
5	Dissolved boneblack	45.36

These phosphates were applied for three seasons, after which no further applications of phosphorus were made, but fertilizers carrying large quantities of nitrogen and potassium were used throughout the test, which was continued for 12 years. All the land was limed at the rate of one ton of quicklime per acre in the spring of 1898. The crops grown during successive seasons were potatoes, wheat, serradella, corn, barley, rye, soybeans, Swedish turnips, corn, oats and cabbage. Excluding the turnip crop, which was affected with disease, the relative efficiency of the different phosphates, taking phosphatic slag as 100, for the average of these crops was found to be as below:[2]

[1]Mass. Hatch Exp. Sta. An. Rpts. 8, 128; 9, 190; 10, 14; 13, 101; 14, 24.
[2]Mass. Hatch Exp. Sta. An. Rpt. 14, 25.

Phosphatic slag	100.0
Raw South Carolina rock	92.3
Dissolved boneblack	90.7
Mona guano	88.3
Florida phosphate	71.5

It will be observed that the phosphorus was applied only at the beginning of the experiment. In commenting on the results of the test the report states that the yields had not been satisfactory during the later years.

In these experiments more than twice as much total phosphorus was given in the slag phosphate as in dissolved boneblack, but in later work it has been shown that there is so little difference in the effectiveness of the pound of phosphorus in basic slag and acidulated phosphate that it would seem that the true explanation of the difference found between these two carriers in this experiment is to be found in the larger quantity given of the slag phosphate. This point must also be considered in comparing the raw rock phosphates with the other materials.

In 1897 the Massachusetts Station began a second experiment,[1] in which different phosphates were compared on the basis of equal annual applications of phosphorus. In this experiment all the land received a fertilizer made up to contain 91.2 pounds of nitrogen and 15.2 pounds of potash annually per acre, the nitrogen being given chiefly in nitrate of soda or sulphate of ammonia with hoof meal added to balance the nitrogen in the bonemeal. The entire field received hydrated lime, applied at the rate of one ton per acre in 1898 and again in 1914, the lime being spread on the plowed land in the spring and harrowed in. To maintain the stock of organic matter in the soil, rye was turned under in 1901, buckwheat in 1912 and rye in 1913, and grasses and clovers were grown in 1905 to 1907 and grass was turned under in 1908. "All fertilizers have been applied broadcast in early spring, and, except when the land was in grass, on the plowed surface and disked in."

"The crops grown during the experiment have been in the order of their succession as follows: corn, cabbage, corn, oats and Hungarian grass (in 1900), onions, cabbage, corn (ensilage), grasses and clovers seeded in spring (no crop harvested), hay, hay, cabbage, soybeans, potatoes, oats and alfalfa (badly winter-killed 1911-12), buckwheat (turned under), corn and corn."

In the following summary table is given the increase over the no-phosphate plots in percentages, as the average for 18 crops harvested in this experiment.

[1]Mass. Exp. Sta. Bul. 162.

TABLE VII.—Massachusetts experiments with carriers of phosphorus. Percentage increase or decrease (—) over yields on land receiving nitrogen and potassium without phosphorus

Crop	Natural mineral phosphates[1]	Basic slag and bonemeal[2]	Acidulated phosphates[3]
	Percent	*Percent*	*Percent*
Corn, 3 years—			
Grain	— 1.48	12.80	17.03
Stover	5.83	17.74	13.22
Hay, 2 years	3.08	8.42	13.24
Onions, 2 years—			
Sound	— 17.75	137.35	160.10
Scallions	12.86	— 25.04	— 16.56
Cabbage, 2 years	116.01	288.30	278.32
Oat hay, 1 year	4.22	27.62	33.63
Hungarian hay, 1 year	4.30	— 5.68	— 6.46
Silage corn, 1 year	— 4.42	25.99	28.00
Soybeans, 1 year —			
Beans	2.54	14.38	14.00
Straw	10.43	35.88	38.26
Potatoes, 1 year	— 2.97	7.49	12.12
Oats and alfalfa hay, 1 year	2.00	47.28	49.37
Alfalfa hay, 1 year	11.49	32.35	9.40

[1]Apatite, Arkansas phosphate, South Carolina rock phosphate, Florida soft phosphate, Navassa phosphate, Tennessee phosphate.
[2]Basic slag meal, raw bonemeal and steamed bonemeal.
[3]Dissolved boneblack, dissolved bonemeal and acid phosphate.

In the average of all the crops the annual gain per acre over the cost of the phosphates was as follows as computed by the experimenters:

Natural mineral phosphates	$ 6.21
Basic slag and bonemeals	36.23
Acidulated phosphates	34.57

No data are given in the bulletin (No. 162) reporting the experiment respecting the separate yields from the different mineral phosphates.

RHODE ISLAND EXPERIMENTS

Bulletin 163 of the Rhode Island Experiment Station gives the results of a 20-year comparison of different carriers of phosphorus, begun at that Station in 1894. In this experiment no regular system of crop rotation was followed, but in some seasons the land was all occupied with ordinary field crops, while at other times it was partly or wholly occupied with truck or garden crops planted in rows crosswise of the plots. During the first half of this test the phosphates were used on the basis of equal cost, but later the work was so readjusted as to put the comparison on the basis of equal weights of phosphorus for the entire experiment, and during the last half only nitrogen and potassium were applied, in order to study the after effects of the treatment. The total amount of phosphorus applied is reported as the equivalent of 738.6 pounds of phosphoric acid per acre, and the total increase for the 20 years is estimated to have had the following values per acre:

TABLE VIII.—Rhode Island experiments with carriers of phosphorus. Total results for 20 years

Phosphates applied in 20 years	Total value of increase	
	On limed land	On unlimed land
Dissolved boneblack, 4,243 lb	$519.50	$420.40
Dissolved bone, 4,589 lb	538.10	468.30
Acid phosphate, 4,821 lb	486.90	440.50
Raw bonemeal, 2,826 lb	508.00	572 70
Basic slag, 4,199 lb	508.50	612.60
Raw phosphate rock, 2,809 lb	269.10	358.80

If acid phosphate is computed at $14 per ton and raw phosphate rock at $10, both spread on the land, the cost of the acid phosphate used in this test would have been $33.75 and that of the raw phosphate, $14.04. After these amounts are deducted, the 20-year net return per acre from these treatments would be as follows:

	20-year average net value of increase	
	On limed land	On unlimed land
From acid phosphate	$453.15	$406.75
From raw phosphate	255.06	344.76

The soil of the Rhode Island Station is extremely acid, and in this experiment half the land has been limed at intervals, while the other half has been left continuously without lime.

The outcome shows that the phosphorus in acid phosphate has produced a greater effect on limed than on unlimed land, while that in raw phosphate has been considerably more effective on the unlimed than on the limed land.

In this test also a single dollar invested in raw phosphate has produced a larger increase than one dollar in acid phosphate, when the two materials have been used on the basis of equal quantities of phosphorus, notwithstanding the much greater increase *per acre* from the acid phosphate; the total returns for one dollar in fertilizers, as computed by the Rhode Island Station, being as shown below:

	Increase for one dollar	
	On limed land	On unlimed land
From acid phosphate	$15.56	$14.07
From raw phosphate	17.36	23.15

During the first 5 years of this test the phosphates were applied on the basis of equal cost, instead of equal quantities of phosphorus, with the outcome shown below:

	Increase for one dollar	
	On limed land	On unlimed land
From acid phosphate	$6.14	$8.38
From raw phosphate	3.12	5.95

The crops grown during this first period were ordinary farm crops, and hence of lower acre-value than the truck crops which followed. Moreover, a large part of the total recovery during the 20 years of this experiment was made after the application of phosphorus had been discontinued, the entire amount of phosphates having been applied during the first 11 years, after which only nitrogen and potassium were given.

	Total value of increase			
	From acid phosphate		From raw phosphate	
	Limed	Unlimed	Limed	Unlimed
First 11 years.....	$241.60	$247.30	$111.80	$188.40
Last 9 years	245.30	193.20	157.30	170.40

The comparison is complicated by the fact that no systematic rotation of crops was followed, and a larger proportion of high acre-value crops may have been grown during one period than during the other, but it illustrates the greater permanancy of effect on limed land, both the acid phosphate and the raw phosphate showing an increasing rate of production on the limed land and a decreasing rate on the unlimed land.

MARYLAND EXPERIMENTS

Bulletins 68 and 114 of the Maryland Experiment Station report a comparison of carriers of phosphorus, begun in 1895 and continued for 12 years, during which period six crops of corn, two of wheat and three of mixed hay were grown, the land being left fallow in 1898.

A summary of the results of this experiment is given in Table IX. This table shows that none of the phosphates produced any appreciable effect on the corn crops, although the wheat and hay show a considerable increase. The acidulated phosphates produced the larger effect on the wheat, while the untreated phosphates seem to have been nearly as effective on the hay crops.

The phosphates were applied in quantities sufficient to give 150 pounds of phosphoric acid per acre, and were apparently given only to the corn crops, but the crops were not grown in systematic rotation, the cropping having been as follows: 1895, corn; 1896, corn; 1897, corn; 1898, fallow; 1899, wheat; 1900, hay; 1901, hay; 1902, corn; 1903, corn; 1904, wheat; 1905, hay; 1906, corn.

TABLE IX.—Maryland experiments with carriers of phosphorus

Plot	Treatment	Average yield per acre				
		Corn, 6 crops		Wheat, 2 crops		Hay, 3 crops
		Grain	Stover	Grain	Straw	
	Crimson clover catch crop	*Bu.*	*Tons*	*Bu.*	*Tons*	*Tons*
1	Double superphosphate	41.2	1.26	24.1	1.30	0.88
2	Dissolved boneblack	40.3	1.27	24.6	1.29	.92
3	Acid phosphate	37.1	1.22	24.6	.92	.95
4	Reverted phosphate	40.3	1.20	22.2	1.14	1.02
5	None	43.7	1.22	13.6	.75	.76
6	Reverted phosphate of iron and alumina	44.0	1.38	23.4	1.06	1.18
7	Untreated boneblack	38.6	1.12	17.5	1.00	.92
8	Raw bonemeal	37.4	1.17	23.2	1.30	.91
9	Basic slag phosphate	35.2	1.08	21.0	1.16	.70
10	None	37.7	1.06	11.1	.65	.71
11	Raw South Carolina rock	38.9	1.17	18.9	1.11	.86
12	Raw Florida soft phosphate	46.7	1 27	18.6	1.10	.97
	No catch crop					
13	Raw bonemeal	39.4	1.34	22.9	1.08	.77
14	Basic slag phosphate	36.5	1.23	21.9	1.28	1.15
15	None	40.5	1.25	12.7	1.09	.60
16	Raw South Carolina rock	41.1	1.32	20.6	1.10	.99
17	Raw Florida soft phosphate	40.7	1.30	17.7	.78	.95
	Rye catch crop					
18	Raw bonemeal	41.9	1.24	25.4	1.29	1.08
19	Basic slag phosphate	45.7	1.36	25.4	1.29	1.07
20	None	41.9	1.20	12.5	.94	.85
21	Raw South Carolina rock	39.2	1.24	20.8	1.00	1.06
22	Raw Florida soft phosphate	40.2	1.24	23.8	.95	.96
	Average results					
	No treatment, Plots 5, 10, 15, 20	39.3	1.18	12.5	.71	.73
	Acidulated phosphates, Plots 1, 2, 3, 4, 6	40.6	1.27	23.8	1.14	.99
	Bonemeal and basic slag, Plots 8, 9, 13, 14, 18, 19	39.3	1.24	23.3	1.23	.95
	Raw rock phosphates, Plots 11, 12, 16, 17, 21, 22.	41.1	1.26	20.1	1.02	.96

On part of the land crimson clover was sown in the corn in July and on another part rye was sown in October, both being turned under the following spring.

Acid phosphate was used in this experiment at the rate of 1,000 pounds per acre on each corn crop, and raw South Carolina rock and Florida soft phosphate at the rate of 530 and 560 pounds, respectively, each dressing calculated to carry 150 pounds of phosphoric acid.

At the Ohio Experiment Station 320 pounds of 14 percent acid phosphate, distributed over the three cereal crops in a 5-year rotation of corn, oats, wheat, clover and timothy, and carrying a total of 45 pounds of phosphoric acid, or 9 pounds annually, has produced, when used alone, a 20-year average increase of 7.78 bushels of corn, 8.79 bushels of oats, 7.58 bushels of wheat, 515 pounds of clover hay and 310 pounds of timothy hay, the whole, including stover and straw, containing approximately 15 pounds of phosphoric acid, or one-third that given in the fertilizer. When the same quantity of acid phosphate has been reinforced with nitrogen and potassium, carried in nitrate of soda and muriate of potash, the increase has reached an average of 18.66 bushels per acre of corn, 18.93 bushels of oats, 15.93 bushels of wheat, 1,407 pounds of clover hay and 988 pounds of timothy hay, the whole containing approximately 35 pounds of phosphoric acid, or nearly 80 percent of that given in the fertilizer.

One hundred and fifty pounds of phosphoric acid is more than is contained in 350 bushels of corn with its cobs and stover, or in 200 bushels of wheat with its straw, and one-third of these quantities of corn or wheat is far greater than any increase over normal yields that can be expected for a term of 10 years. It is evident, therefore, that soluble phosphorus has been given in this experiment in quantities beyond any reasonable expectation of utilization, and therefore that the yields produced by this treatment cannot be taken as a standard by which to measure the increase produced by the other carriers of phosphorus.

On the other hand, a dressing of 320 pounds of raw phosphate rock, used alone for 11 years at the Ohio Station in a 3-year rotation of corn, oats and clover, to be more fully described farther on, has produced increase containing nearly 3½ pounds of phosphoric acid.

Apparently the raw phosphates used in the Maryland experiments have increased the corn yield by an average of 1.8 bushel, the wheat by 7.6 bushels, and the hay by 0.23 ton, or 460 pounds, which would account for about 7½ pounds of phosphoric acid, a slightly larger rate of increase than that shown in the Ohio test. It seems probable, therefore, that in the Maryland test the raw phosphates have produced their full effect and that the acidulated phosphates have been used in quantities far greater than the soil and the crops were able to utilize.

ILLINOIS EXPERIMENTS

In *The Prairie Farmer* for February 26, 1916, Dr. C. G. Hopkins reports the results of three experiments made by the Illinois Experiment Station on outlying fields during the 12 years, 1904 to 1915, inclusive, on corn, oats and wheat grown in rotation with clover. In these experiments the straw and stover were returned to part of the land and part was limed.

The phosphates were applied but once in each rotation, but in quantities sufficient to make an annual application of 200 pounds of steamed bonemeal per acre, 333 pounds of acid phosphate, 666 pounds of raw phosphate rock and 260 pounds of basic slag phosphate. The total value of the crops resulting from the different treatments, as computed by Dr. Hopkins, is shown in Table X.

TABLE X.—Illinois phosphate experiments. Crop values per acre

Prices per bushel: Corn, 50 cents; oats, 40 cents; wheat, $1; clover seed, $10; hay, $10 per ton						
Phosphate used	Bone	None	Acid	Rock	None	Slag
With residues and potassium, Odin Field, 1904 to 1915						
With lime, 11 crops	$177.56	$147.46	$158.11	$172.92	$155.06	$181.93
Without lime, 11 crops	155.34	122.71	143.91	135.67	107.51	137.64
Total, 23 crops	$341.94	$279.93	$312.86	$319.15	$273.53	$329.65
With residues and potassium, Mascoutah Field, 1904 to 1913						
With lime, 6 crops.	$145.57	$128.36	$140.89	$151.16	$132.50	$153.31
Without lime, 6 crops	154.61	120.19	137.95	145.86	116.46	148.85
Total, 14 crops	$328.80	$274.71	$306.40	$324.54	$275.86	$327.50
With lime and potassium, Cutler Field, 1904 to 1915						
With residues, 12 crops	$201.93	$204.88	$223.09	$232.49	....	....
No residues, 12 crops	....	180.95	242.79	204.04	....	....
All fields						
With residues, 49 crops	$872.67	$759.52	$ 842.35	$ 876.08	....	....
Increase for phosphorus	113.15	....	82.83	116.56	....	....
All trials, 61 crops	....	940.47	1085.14	1080.12	....	....
Increase for phosphorus	....	....	144.67	139.65	....	....

Note—The term "residues" means cornstalks, straw and cover crops plowed under.

Computing raw phosphate rock at $7.50 per ton, in bulk carloads delivered at average points between the Ohio River and the Lakes, and rating 16 percent acid phosphate at $12.50 under the same conditions, a price at which it was purchasable before the derangement of values incident to the European War, and adding $2.50 per ton in each case for hauling from railway station to farm and spreading on the land, we find that the cost of the 666 pounds of raw phosphate rock applied per acre in these tests would have been $3.33, and that of the 333 pounds of acid phosphate would have been $2.50. The total cost of the acid phosphate, therefore, for the 61 crops would have been $152.50, and that of the raw phosphate rock, $203.13, as against an increase of $144.67 for acid phosphate and of $139.65 for raw phosphate rock. Apparently the rate of application has been beyond the requirements of the soil or else greater than the capacity of the crops to utilize the phosphorus in the absence of nitrogen.

INDIANA EXPERIMENTS

Bulletin 187 of the Purdue University Agricultural Experiment Station reports a series of cooperative experiments in the comparison of acid phosphate with raw rock phosphate, begun in 1904, most of which, however, were discontinued at the end of the first or second season. In 1905 more permanent experiments were started at Littles, in Pike County, "on a yellowish brown, silt loam soil of medium fertility," and at Scottsburg, in Scott County, on a Volusia silt loam, the system of cropping in both cases being a 3-year rotation of corn, wheat and clover, each crop being grown every year. When the clover failed cowpeas or soybeans were substituted. The land was plowed once in three years for corn, except when the clover failed, when it was also plowed for the cowpeas or soybeans. The wheat was drilled on disked corn-stubble and the clover was seeded on the wheat in the spring.

"The fields were laid out in the fall of 1905, when the first wheat crop was sown. The various treatments were all applied to the wheat in the first round of the rotation on each series of plots. The manure was applied at the rate of 10 tons per acre. The raw rock phosphate, containing 28 percent of phosphoric acid, was applied at the rate of one ton per acre. The acid phosphate was drilled with the wheat at the rate of 150 pounds per acre of 16 percent goods. The manure and rock phosphate were applied after plowing and disked into the surface soil. After the first round of the rotation, the manure treatment was repeated on every corn crop and the acid phosphate on every wheat crop. A second ton of raw rock phosphate, containing 30 percent of phosphoric acid, was applied for corn and cowpeas on Series A and B in 1911, and on Series C in 1912, when this series was planted to cowpeas in place of the clover which had failed. Both fields were limed in 1911 at the rate of two tons of finely ground limestone per acre."

The average outcome of these experiments is given in Table XI, which shows that both the total and the net returns have been greater from acid phosphate than from the raw rock phosphate.

TABLE XI.—Indiana experiments with carriers of phosphorus

Treatment	Average yield per acre					Annual value of produce*	Annual value of increase*	Annual cost of treatment†	Annual gain or loss(—)
	Corn, 8 crops		Wheat, 10 crops		Hay, 3 crops				
	Grain	Stover	Grain	Straw					
	Bushels	*Tons*	*Bushels*	*Tons*	*Tons*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Littles Field									
None	41.8	1.65	13.3	0.57	1.99	18.98	....	....	....
Acid phosphate	41.9	1.64	15.0	.70	2.18	20.20	1.57	1.13	0.44
Raw phosphate	39.2	1.51	14.7	.65	1.96	18.78	.51	2.00	—1.49
None	37.7	1.50	13.7	.56	1.88	17.92	....	....	....
Manure and raw phosphate	46.9	1.72	18.6	.88	2.46	23.15	4.80	5.33	— .53
Manure	47.4	1.85	18.4	.88	2.02	21.81	3.05	3.33	— .28
None	41.0	1.71	14.9	.75	1.90	19.19	....	....	....
Scottsburg Field									
None	25.1	1.18	9.2	.43	.37	9.21	....	....	....
Acid phosphate	34.3	1.41	15.6	.69	.71	13.99	4.03	1.13	2.90
Raw phosphate	40.4	1.49	13.9	.66	.70	14.56	3.85	2.00	1.85
None	30.5	1.29	10.2	.50	.65	11.46	....	....	....
Manure and raw phosphate	51.2	2.06	20.8	1.07	1.58	21.95	10.34	5.33	5.01
Manure	50.5	2.01	20.0	1.04	1.53	21.39	9.64	3.33	6.31
None	30.5	1.29	10.4	.53	.76	11.90	....	....	....

*Computing corn at 50 cents a bushel, wheat at 80 cents, stover and straw at $2 50 a ton and hay at $10 a ton. †Computing raw rock phosphate at $7.50 a ton and 16 percent acid phosphate at $12.50 a ton, both in bulk carloads, with $2.50 a ton added to cover cost of application. Manure is computed at $1 a ton.

In these experiments the acid phosphate has been applied in small quantity, only 150 pounds on the three crops of the rotation, equivalent to 50 pounds annually, while the raw phosphate has been given in two large doses of a ton each, applied 6 years apart. If the phosphorus in the raw rock is in a condition to be gradually made available in the soil as the crops require it this mode of application should be at least as favorable as more frequent distribution in smaller quantities would be, but it seems that the effectiveness of both carriers of phosphorus has been very low.

In 1911 two new experiments were located, one at North Vernon, in Jennings County and the other at Worthington, in Greene County, in which further comparisons are being made between the two phosphates. These experiments have not yet been carried long enough to justify definite conclusions, but thus far they seem to be corroborating the results of the Littles and Scottsburg tests.

GERMAN EXPERIMENTS

The following abstract of a report by T. Remy (in Landw. Jahrb. 40 (1911) No. 3-4, pp. 559-611) was published in the Experiment Station Record (XXV, p. 631):

"Comparative tests of Thomas slag and Algerian, Lahn and Florida phosphates in field and pot experiments with grasses, grains, peas, lupines and mustard are reported.

"Except in a few cases with winter grain and lupines the raw phosphate was inferior as a fertilizer to Thomas slag. Thomas slag was from 63.8 to 76.6 percent as effective as superphosphate, and Algerian phosphate from 5.5 to 12.8 percent as effective. The results with Florida and Lahn phosphates were not materially different from those with the Algerian phosphate. The use of the insoluble phosphates in connection with decaying organic matter or sodium bisulphate greatly increased their efficiency."

OHIO EXPERIMENTS

C. E. THORNE, C. G. WILLIAMS AND J. W. AMES

The Ohio Station began in 1897 an experiment in the comparison of acid phosphate, raw Tennessee rock phosphate and other materials as reinforcements of barnyard manure. The plan of this treatment is given in Bulletin 183, and the results up to 1913 are summarized in Circular 144.

Briefly stated, both fresh manure and that which has been exposed to the weather for some months are treated with the two phosphates, used at the uniform rate of 40 pounds to the ton of manure. The manures are spread on clover sod, the fresh manure in the fall or early winter and the yard manure in the spring, and both are plowed under in April for corn. The corn is followed by wheat and clover in a 3-year rotation, without any further manuring or fertilizing. Three tracts of land are used in the experiment, so that each crop is grown every season. The land is divided into plots of one-sixteenth acre, and every third plot is left continuously without any manure or fertilizer.

The arrangement of the plots in this test is shown in Diagram I, which also shows the general treatment of all the plots. The different sections are separated by roadways 20 feet wide, which are kept permanently in grass, and the two blocks of each section are separated by a strip 30 feet wide which receives no treatment. The crops are planted across this strip but are harvested separately. In each section Plots 1 and 11, 2 and 12, etc. are continuous, the ends being separated by this 30-foot strip. Paths 2 feet wide separate the different plots.

At the beginning of the experiment the plots were plowed separately, thus being slightly ridged, with a furrow between, which provided shallow surface drains and impeded the crossing of plant roots from unmanured to manured land. During later years the plowing has been across the plots and the ridges have become obliterated, but the sharp differences in yield between the manured and unmanured land show that there has been practically no cross-feeding.

In Table XII are given the average yields per acre obtained in this experiment for the 19 years, 1897-1915.

If raw phosphate rock is estimated at $7.50 per ton and 14 percent acid phosphate at $11.50—prices at which the two materials could have been purchased in bulk carloads delivered at central Ohio points before the European War and $2.50 per ton is added for the cost of hauling from railway station to farm and spreading, the acre-cost of the raw phosphate rock, as used in this experiment, would be $1.60, and that of the acid phosphate, $2.24.[1]

Deducting one-third of these costs from the average annual values shown in Table XII would leave $27.41 as the average net return per acre from the manure reinforced with raw phosphate rock, and $27.57 from that treated with acid phosphate.

[1]In earlier reports on this experiment raw phosphate was rated at its cost in bulk carloads on track, and acid phosphate at its retail cost in sacks, the cost of sacking and of hauling from railway to farm and distributing being overlooked; but it costs just as much to haul out and distribute the one material as the other and sacking is no more necessary for the one than for the other.

PLOTS ONE-SIXTEENTH ACRE

Plot	Treatment	Section	Treatment	Plot
11	Nothing	SECTION A	Nothing	1
12	Yard manure and gypsum		Yard manure and floats	2
13	Stall manure and gypsum		Stall manure and floats	3
14	Nothing		Nothing	4
15	Yard manure, untreated		Yard manure and acid phos.	5
16	Stall manure, untreated		Stall manure and acid phos.	6
17	Nothing		Nothing	7
18	Chemical fertilizer		Yard manure and kainit	8
19	Chemical fertilizer		Stall manure and kainit	9
20	Nothing		Nothing	10
11	Nothing	SECTION B	Nothing	1
12	Yard manure and gypsum		Yard manure and floats	2
13	Stall manure and gypsum		Stall manure and floats	3
14	Nothing		Nothing	4
15	Yard manure, untreated		Yard manure and acid phos.	5
16	Stall manure, untreated		Stall manure and acid phos.	6
17	Nothing		Nothing	7
18	Chemical fertilizer		Yard manure and kainit	8
19	Chemical fertilizer		Stall manure and kainit	9
20	Nothing		Nothing	10
11	Nothing	SECTION C	Nothing	1
12	Yard manure and gypsum		Yard manure and floats	2
13	Stall manure and gypsum		Stall manure and floats	3
14	Nothing		Nothing	4
15	Yard manure, untreated		Yard manure and acid phos.	5
16	Stall manure, untreated		Stall manure and acid phos.	6
17	Nothing		Nothing	7
18	Chemical fertilizer		Yard manure and kainit	8
19	Chemical fertilizer		Stall manure and kainit	9
20	Nothing		Nothing	10

NORTH

Diagram I.—Experiments in the reinforcement of manure.
Arrangement of plots and plan of fertilizing

It will be observed that there is a progressive reduction in the yield of the unfertilized plots from 1 to 7. If this means that the fertility of the soil has diminished regularly from Plot 1 to Plot 7, then the total yields, as shown in Table XII, would not be a true measure of the effect of the different treatments.

TABLE XII.—Experiments in the reinforcement of manure. 18-year average yield per acre, 1897-1915

Plot	Treatment	Corn		Wheat		Hay	Annual value of produce
		Grain	Stover	Grain	Straw		
		Bu.	*Lb.*	*Bu.*	*Lb.*	*Lb.*	*Doll.*
1	None	40.62	2,365	13.28	1,543	3,020	16.97
2	Yard manure and raw phosphate	63.40	3,464	24 94	2,674	4,357	27.04
3	Stall manure and raw phosphate	66.75	3,677	26.46	2,869	4,765	28.85
4	None	32.38	2,050	11.75	1,370	2,299	13.78
5	Yard manure and acid phosphate	63.69	3,372	26.57	2,907	4,260	27.42
6	Stall manure and acid phosphate	67.04	3,578	27.06	3,031	4,851	29.22
7	None	31.16	1,982	10.90	1,319	2,314	13.33
8	Yard manure and kainit	56.67	3,232	21.52	2,423	3,547	23.28
9	Stall manure and kainit	61.54	3,475	23.13	2,691	4,238	26.06
10	None	34.14	2,049	11.14	1,364	2,488	14.23
11	None	38.97	2,375	14.40	1,732	3,251	17.46
12	Yard manure and gypsum	60.62	3,400	24.39	2,712	3,885	25.63
13	Stall manure and gypsum	61.48	3,498	24.31	2,695	3,909	25.82
14	None	31.77	2,037	11.29	1,334	2,354	13.63
15	Yard manure untreated	52.85	2,921	20.72	2,296	3,337	22.07
16	Stall manure untreated	59.37	3,271	22.03	2,494	4,000	24.84
17	None	37.94	2,331	11.59	1,409	2,694	15.46
18	Chemical fertilizers	47.78	2,690	16.16	1,841	3,163	19.43
19	Chemical fertilizers	45.20	2,494	15.42	1,885	3,255	18.89
20	None	33.88	2,028	10.72	1,382	2,679	14.39
	Av. from manure and raw phos.	65.07	3,570	25.70	2,771	4,561	27.94
	Av. from manure and acid phos.	65.36	3,475	26.81	2,969	4,555	28.32
	Av. from manure untreated	56.11	3,096	21.37	2,395	3,668	23.45
	Av. unmanured yields	34.77	2,153	11.76	1,395	2,536	14.61

During the 19 years since this experiment was begun six crops each of corn and wheat and five crops of hay have been grown on each of the three tracts of land included in the test, one crop of corn having been lost because of injury from grub worms, and soybeans having been grown instead of clover the first 3 years and plowed under. These 51 crops are arranged by sections in Table XIII, the work thus being treated as three separate experiments.

This table shows that if we disregard the irregularities of the soil, as shown by the variations in the unfertilized yields, and consider only the general level of the effect of the treatments, as shown in the final column, there is not enough difference in the outcome to justify the conclusion that either raw phosphate or acid phosphate has been materially superior to the other, although the differences between yard manure and stall manure, as shown in the body of the table, are sufficiently uniform to be accepted as a positive demonstration of the superiority of the fresh manure.

TABLE XIII.—Experiments in the reinforcement of manure, arranged by sections

Plot	Average yield per acre					Annual value per acre	Average values
	Corn		Wheat		Hay		
	Grain	Stover	Grain	Straw			
				Section A			
	Bu.	*Lb.*	*Bu.*	*Lb.*	*Lb.*	*Doll.*	*Doll.*
1	32.56	2,137	13.25	1,798	2,832	15.32	....
2	59.54	3,401	23.62	2,892	4,427	26.22	27.24
3	61.86	3,583	26.18	3,240	4,875	28.26	
4	23.96	1,831	12.45	1,503	2,338	12.60	....
5	55.22	3,268	25.01	3,000	4,175	25.44	26.65
6	61.21	3,516	26.35	3,218	4,693	27.86	
7	21.29	1,607	12.38	1,537	2,247	11.90	....
8	49.11	3,127	24.47	3,001	3,609	23.28	24.82
9	54.71	3,308	26.42	3,233	4,482	26 36	
10	23.46	1,737	14.23	1,738	2,172	12.77	....
11	24.20	1,964	14.34	1,859	2 835	14.17	....
12	48.86	3,185	22.71	2,914	3,696	22.90	23.97
13	52.17	3,369	24.40	3,074	4,294	25 04	
14	23.19	1,906	12.61	1,563	2,519	12.87	....
15	42.15	2,639	21.41	2,619	3,686	21.14	22.87
16	50.87	3,012	23.07	2,889	4,509	24.60	
17	25.34	1,868	11.55	1,544	2,654	13.15	....
20	22.05	1,569	13.09	1,719	2,774	13.16	....
				Section B			
1	46.57	2,772	13.04	1,465	2,461	17.11	....
2	72.30	4,104	26.11	2,637	4,061	28.59	29.32
3	76.54	4,315	26.73	2,839	4,316	30.06	
4	44.07	2,641	13.46	1,561	2,499	16.85	....
5	74.11	3,889	28.27	3,065	4,185	29.76	29.50
6	73.84	3,782	26.32	2,949	4,269	29.24	
7	40.31	2,476	10.42	1,297	2,214	14.76	....
8	64.72	3,704	19.10	2,159	3,253	23.74	24.55
9	69.27	3,762	19.60	2,452	3,603	25.37	
10	49.45	2,648	11.21	1,493	2,892	17.78	....
11	44.17	2,515	13.58	1,672	2,876	17.52	....
12	67.83	3,700	24.58	2,658	3,625	26.55	26.44
13	70.69	3,837	23.17	2,552	3,433	26.34	
14	42.93	2,474	12.60	1,536	2,507	16.36	....
15	64.66	3,509	20.49	2,432	3,188	24.03	25.25
16	68.61	3,768	21.87	2,554	3,939	26.47	
17	52.57	2,763	14.11	1,767	3,132	19.93	....
20	47.71	2,667	10.97	1,575	3,113	17.80	....
				Section C			
1	42.72	2,187	13.52	1,365	3,766	18 48	....
2	58.37	2,888	25.08	2,493	4,583	26.30	27.26
3	61.84	3,133	26.47	2,529	5,103	28.23	
4	29.11	1,678	9.35	1,047	2,060	11.91	....
5	61.74	2,959	26.43	2,657	4 420	27.04	28.81
6	66.07	3,437	28.51	2,927	5,591	30.58	
7	31.86	1,869	9.91	1,123	2,480	13.33	....
8	54.95	2,865	20.99	2,109	3,779	23.12	24.77
9	60.65	3,359	23.38	2,389	4,629	26.45	
10	29.51	1,762	7.99	859	2,399	12.14	....
11	48.52	2,645	15.28	1,664	4,052	20.71	....
12	65.17	3,315	25.87	2,563	4,334	27.43	26.75
13	61.58	3,286	25.35	2,457	4,000	26.08	
14	29.19	1,732	8.68	895	2,037	11.67	....
15	51.75	2,615	20.25	1,838	3,137	21.11	22.32
16	58.62	3,033	21.50	2,038	3,551	23.53	
17	35.92	2,102	9.08	917	2,295	13.49	....
20	31.87	1,847	7.93	852	2,351	12.47	....

TABLE XIV.—Experiments in the reinforcement of manure. 19-year average increase per acre as computed by progressive averages—arranged by sections

Plot	Manure and treatment	Corn		Wheat		Hay	Annual value of increase	Average values
		Grain	Stover	Grain	Straw			
	Section A							
		Bu.	*Lb.*	*Bu.*	*Lb.*	*Lb.*	*Doll.*	*Doll.*
2	Yard and raw phosphate.........	29.85	1,366	10.64	1,192	1,760	11.81	13.28
3	Stall and raw phosphate........	33.03	1,650	13.46	1,639	2,372	14.75	
5	Yard and acid phosphate.........	32.15	1,512	12.58	1,486	1,867	13.07	14.39
6	Stall and acid phosphate..........	39.03	1,834	13.95	1,692	2,416	15.72	
8	Yard and kainit.........	27.10	1,477	11 47	1,397	1,387	11.08	12.47
9	Stall and kainit....	31.97	1,614	12.81	1,562	2,285	13.57	
12	Yard and gypsum	24.32	1,240	8.95	1,154	966	9.05	10.39
13	Stall and gypsum................	28.64	1,444	11.21	1,412	1,670	11.74	
15	Yard untreated...	18.24	746	9.15	1,062	1,122	8.10	9.82
16	Stall untreated...	26.25	1,131	11.17	1,339	1,900	11.55	
	Section B							
2	Yard and raw phosphate........	26.56	1,376	12.92	1,140	1,587	11.57	12.34
3	Stall and raw phosphate..........	31.64	1,630	13.41	1,310	1,830	13.12	
5	Yard and acid phosphate.........	31.29	1,303	15.82	1,592	1,781	13.61	13.70
6	Stall and acid phosphate..........	32.28	1,251	14.89	1,564	1,960	13.79	
8	Yard and kainit..................	21.36	1,171	8.42	797	813	7.98	8.28
9	Stall and kainit..................	22.87	1,171	8.65	1,024	937	8.59	
12	Yard and gypsum.......	24.07	1,199	11.33	1,031	872	9.42	9.50
13	Stall and gypsum.................	27.35	1,349	10.24	971	803	9.59	
15	Yard untreated...................	18.52	939	7.39	819	473	6.58	7.25
16	Stall untreated....................	19.25	1,101	8.26	864	1,015	7.92	
	Section C							
2	Yard and raw phosphate.........	20.19	871	12.95	1,234	1,386	10.01	12.07
3	Stall and raw phosphate..........	28.19	1 285	15.73	1,376	2,474	14.13	
5	Yard and acid phosphate.........	31.71	1,217	16.89	1,585	2,220	14.66	16.19
6	Stall and acid phosphate..........	35.13	1,632	18.79	1,829	3,251	17.73	
8	Yard and kainit..................	23.88	1,062	11.72	1,074	1,329	10.21	12.06
9	Stall and kainit..................	30.36	1 561	14.75	1,442	2,200	13.91	
12	Yard and gypsum	23.09	1,074	12.79	1,155	954	9.78	10.59
13	Stall and gypsum.................	25.95	1,250	14.47	1,306	1,291	11.40	
15	Yard untreated..................	20.32	760	11.44	936	1,014	8.84	9.66
16	Stall untreated...................	24.94	1 054	11.95	1,128	1,342	10.49	

However, if we plot these results as shown in Diagrams II and III we shall see that the variations in original fertility of the soil have followed a regular course on each section and for each crop, and that if we take these variations into consideration a different result will be reached. This is done in Table XIV, in which the increase for each treatment is computed on the assumption that the variations in the natural productiveness of the soil are more likely to be gradual than abrupt, and that if Plots 1 and 4, untreated, yield

30 and 33 bushels, respectively, the probable unaided yields of Plots 2 and 3 would be 31 and 32 bushels. Computed in this way the variations in increase between the two phosphate treatments are as regular as those between the two manure treatments, and on each of the three sections the increase from acid phosphate over that produced by raw phosphate is more than sufficient to cover the larger cost of the acid phosphate, at the prices prevailing during the period under review.

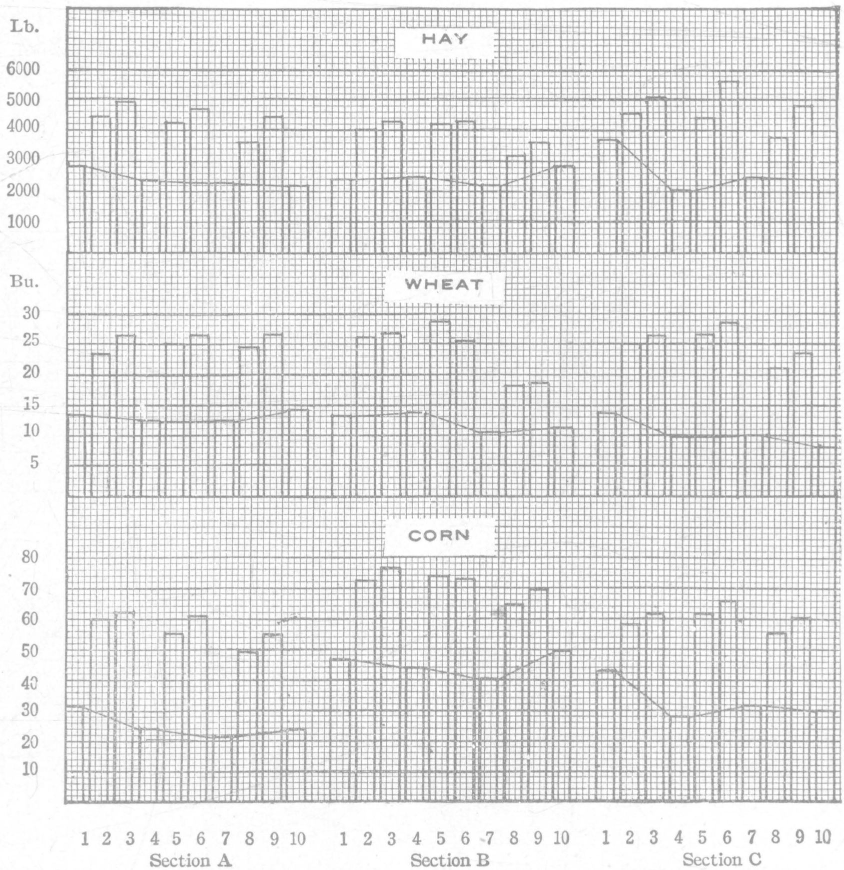

Diagram II.—Experiments in the reinforcement of manure, 19-year average yields per acre

Diagrams II and III show the relative average yields on each section of the different crops for the entire period of the experiment, and Diagram IV is a composite picture of the entire experiment, showing the relative positions of the different plots with reference to each other and also the comparative average annual value per acre of the produce of each plot during the 19 years of the experiment. On Section A there has been comparatively small difference in the yields of the unfertilized plots. On Section B the yields on Plot 10 are higher than those on Plot 7, while on Section C the yields on Plots 1 and 11 are decidedly higher than those on the remaining unfertilized plots, thus indicating a higher degree of fertility on the eastern end of Section B and the western side of Section C than on the remainder of either section, as would be expected from a study

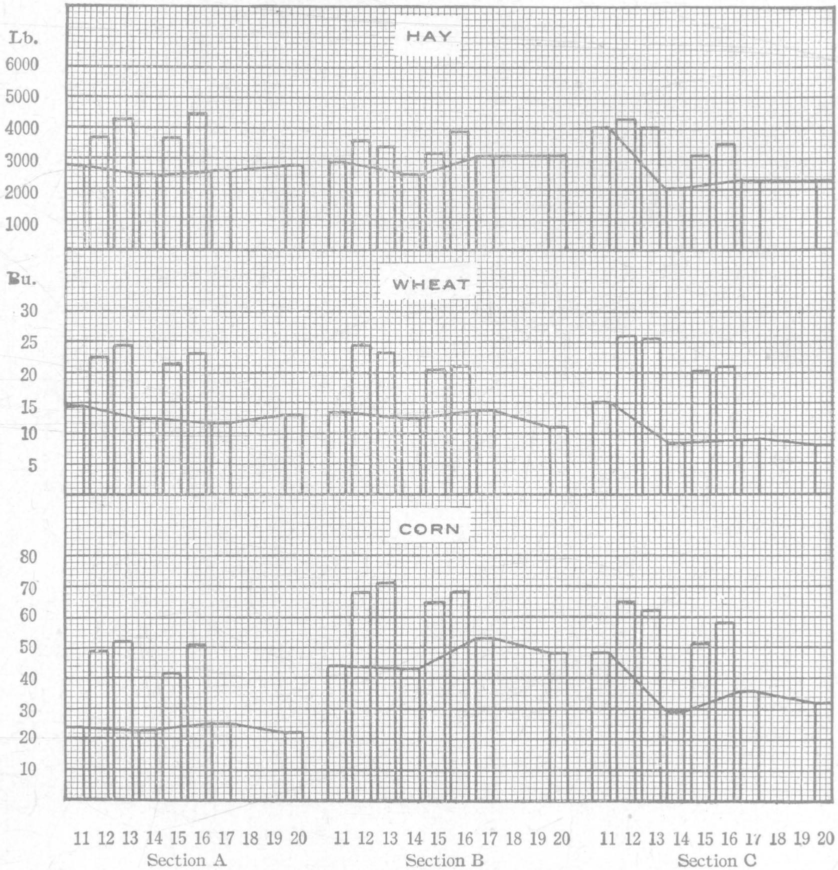

Diagram III.—Experiments in the reinforcement of manure, 19-year average yields per acre

of the contour map, shown as Diagram V. This map somewhat exaggerates the difference in level, as the contour lines represent differences of only one foot, but it shows that Sections B and C are located on low ridges, with a little valley between. The difference in altitude between the crests of these ridges and the valley between them is only about one fcot in the deepest part, as measured directly east and west, or about one percent, but it is enough to have caused some transfer of fertility in the early history of the field.

We have suggested (Circular 120, p. 112) the possibility that the land now included in Plots 1 and 11, Section C, may at one time have been occupied by a fence, thus conserving its fertility, but we have no history of such occupation and the superior productiveness of the adjoining plots of Section B indicates that the larger yields on these plots are due to natural variations of soil.

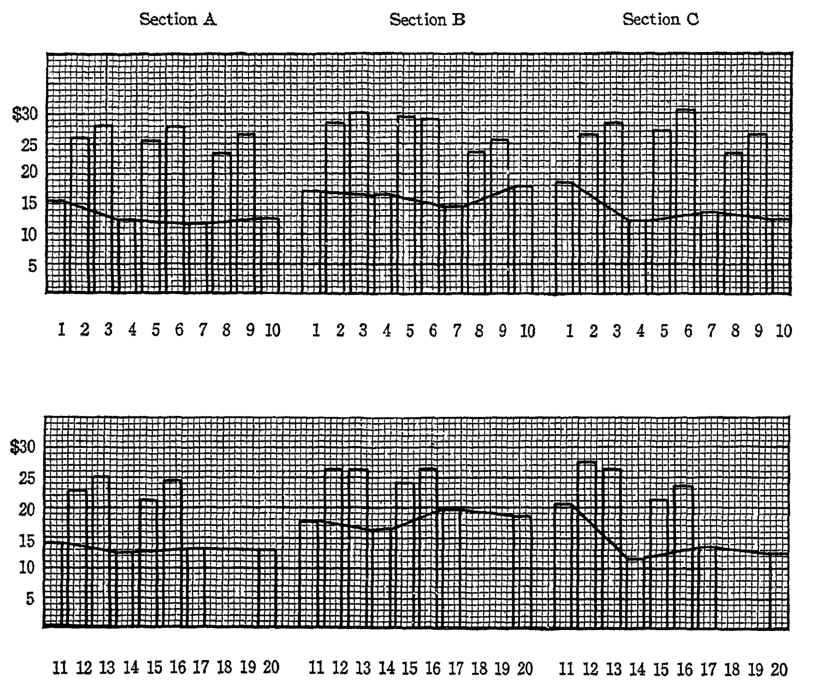

Diagram IV.—A composite of Diagrams II and III, showing the relative positions of the plots and the 19-year average annual value per acre of the produce of each plot

In June, 1916, the quantity of nitrogen per acre in the upper 7 inches of this soil was determined for Plots 1 to 10 of each section, with the results shown in Table XV and Diagram VI (page 258). In the diagram the upper curve and the lines projecting above it show the pounds of nitrogen for 1916, and the lower one, the average annual value of the unfertilized crops for the 19 years, 1897-1915.

With the exception of the small discrepancies in Plot 7 of Section A and Plot 1 of Section B, there is a general parallelism between these curves.

The lower range of nitrogen in Section A than in either of the others may be due to the fact that, at the time of sampling, Section A was in wheat, while Section B was in clover and Section C in corn growing on a recently turned clover sod. The lower range of crop values is probably due to seasonal variation.

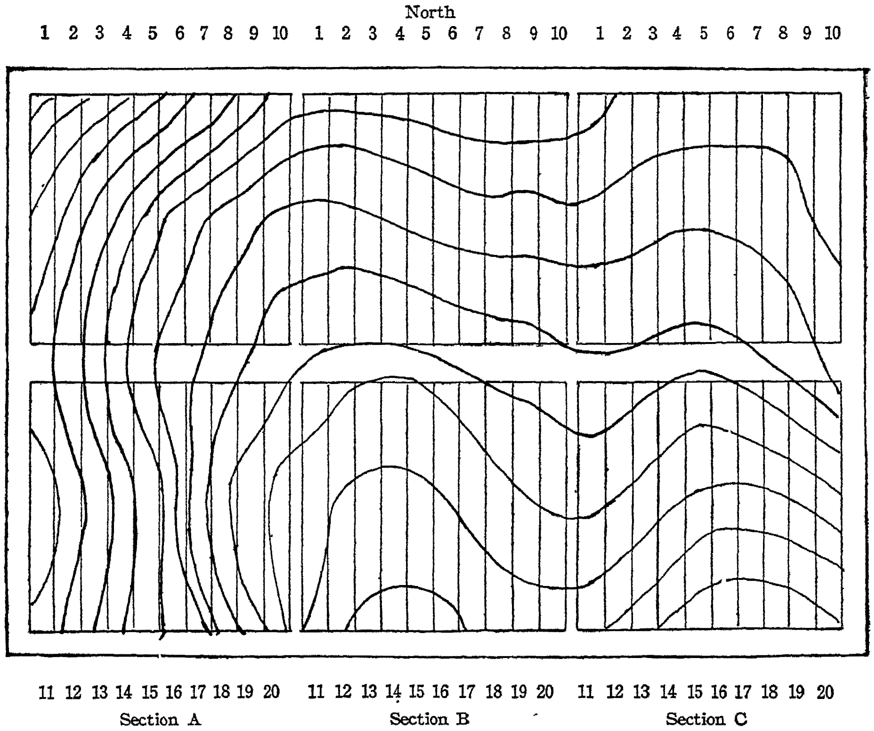

Diagram V.—Contour map of experiment field. Contour lines represent differences in level of one foot.

The decided rise in both the nitrogen and crop-value lines on both sides of the road separating Sections B and C shows that there is a strip here of probably 50 feet or more in width which is superior in fertility to the land on either side. Additional determinations of nitrogen across the unfertilized strip separating the two blocks of Section C show for Plot 2, 2,474 pounds per acre, and for Plot 3, 2,244 pounds. The calculated quantities for these plots, on the assumption of a gradual change in fertility, would be 2,436 pounds and 2,248 pounds, had they been left unmanured.

TABLE XV.—Experiments in the reinforcement of manure. Pounds of nitrogen per acre in surface 7 inches of soil, 1916

Plot	Manure and treatment	Sec. A	Sec. B	Sec. C
1	No manure	1,790	2,050	2,624
4	" "	1,650	2,170	2,060
7	" "	1,760	2,150	2,190
10	" "	1,684	2,504	2,014
	Yard manure with:			
2	Raw phosphate	1,890	2,360	2,480
5	Acid phosphate	2,020	2,374	2,390
8	Kainit	2,020	2,420	2,340
	Stall manure with:			
3	Raw phosphate	2,090	2,330	2,400
6	Acid phosphate	1,984	2,304	2,360
9	Kainit	2,030	2,434	2,384

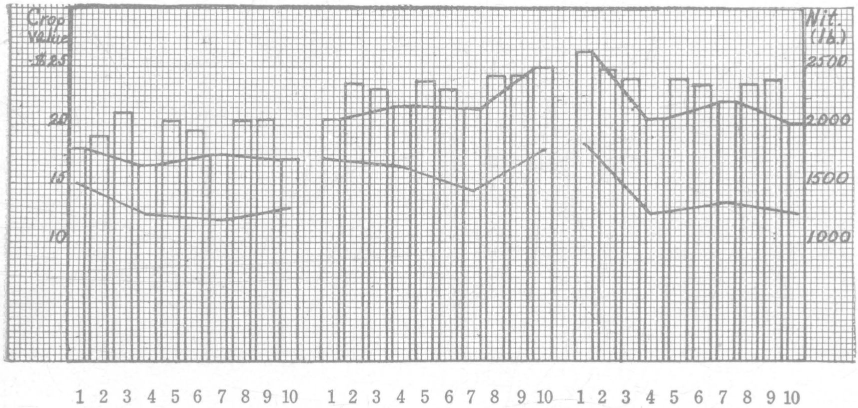

Diagram VI.—Experiments in the reinforcement of manure: pounds of nitrogen per acre in June, 1916, and 19-year average value of crops per acre

Diagrams II and III show on each section 15 comparisons between yard manure and stall manure—five for each of the three crops—or 45 such comparisons in the three sections. It is interesting to observe that whenever stall manure falls below yard manure in total yield the lines connecting the adjoining unmanured plots drop from the check on the yard manure side to the one on the stall manure side.

Sometimes a drop of this character occurs and still the stall manure stands highest, Plots 2 and 3 of Section C being conspicuous examples; but it will be seen that as a rule there is some connection between these heights and the unmanured yields adjoining. In the case of Plots 12 and 13 on Section C, which are the extensions of

Plots 2 and 3, this connection is so sharply marked that if we consider the total yields alone the stall manure will fall behind the yard manure on this section in each of the three crops; but, when the increase is computed by the rule employed in all this work, we find that the stall manure has shown its usual superior effectiveness on these plots also.

A field experiment with barnyard manure involves peculiar difficulties. The composition of the manure varies with the character of the feed and with the amount of bedding used, and when the experiment involves exposure to the weather the character of the weather during the period of exposure adds another variable factor. With hand spreading it is practically impossible to secure uniform distribution of manure, and with the best machines there will be some variations in distribution. Added to all this is the fact that in the most uniform soils there are differences of texture or of topography that result in unequal distribution of moisture, which often is a more potent factor in controlling crop yields than the quantity of available plant food. For these reasons an experiment with manure must be carried through a long period of years before it can have any scientific value, and to attempt to draw conclusions from any single season's results may lead away from, instead of toward the truth.

In 1905 Section B received a dressing of caustic lime, applied to manured and unmanured land alike at the rate of 1 ton per acre. In 1906 and 1907 Sections A and C received ground raw limestone, at the rate of 2 tons per acre, after which the dressing was reduced to 1 ton per acre as each section came under corn, until 1913, when the rate was increased to 2 tons.

By reference to Diagram VII it will be seen that the liming apparently produced an immediate increase in the yield of clover and that the corn yields began to increase as soon as this crop received the secondary effect due to the increased clover yields. Wheat, however, had begun to show an increase in yield several years before the liming was begun. In connection with these results the course of crop production in Wayne County as a whole is given in Diagram VIII, which shows that other causes, in part seasonal and in part due to a larger use of fertilizers and lime over the county, have operated to produce a general increase in wheat yields in the vicinity of the Experiment Station, although the corn yield has remained practically stationary.

The points brought out in Diagram VII are shown in another form in Table XVI, which gives the yield and increase obtained in this experiment in two 9-year periods, the data including the average values in each period of nine crops of corn (1897 to 1905 and 1906 to 1915, excluding the crop of 1909), nine crops of wheat (1898 to 1906 and 1907 to 1915), seven crops of hay in the first period (1901 to 1907) and eight crops in the second period (1908 to 1915).

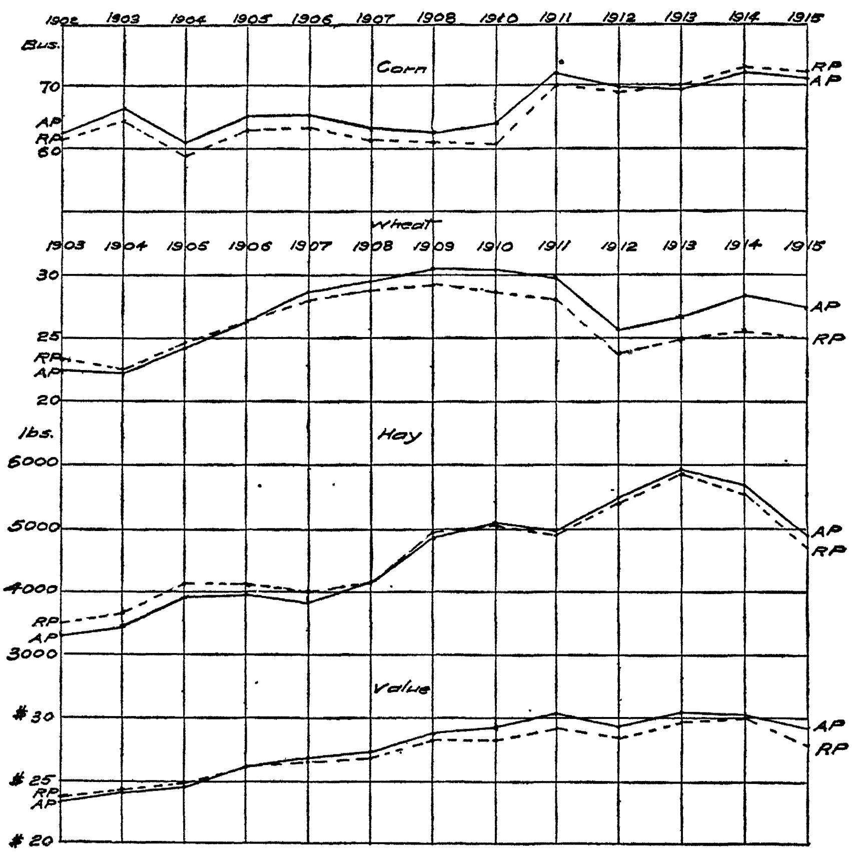

Diagram VII.—Yields in manure test by 6-year averages. Each point in these curves represents the average yield for the 6-year period ending on that date. AP=Acid phosphate; RP=Raw phosphate.

TABLE XVI.—Experiments in the reinforcement of manure. Average annual values per acre by 9-year periods

Plot	Treatment	First period		Second period	
		Total yield	Increase	Total yield	Increase
1	None	$15.11	....	$18.69	....
2	Yard manure and raw phosphate	24.68	$10.37	29.25	$11.87
3	Stall manure and raw phosphate	26.99	13.47	30.61	14.55
4	None	12.72	....	14.75	....
5	Yard manure and acid phosphate	24.44	11.89	30.22	15.61
6	Stall manure and acid phosphate	26.72	14.33	31.77	17.31
7	None	12.22	....	14.32	....
8	Yard manure and kainit	21.55	8.95	25 08	10.53
9	Stall manure and kainit	24.45	11.48	27.55	12.77
10	None	13.35	....	15.01	....
11	None	15.84	....	18.84	....
12	Yard manure and gypsum	23.44	8.76	27.68	10.22
13	Stall manure and gypsum	23.67	10.14	27.83	11.74
14	None	12.37	....	14.71	....
15	Yard manure untreated	19.20	6.34	24.75	9.25
16	Stall manure untreated	21.94	8.59	27.54	11.26
17	None	13.84	....	17.07	....
18	Chemical fertilizer	16.81	3.00	21.95	5.60
19	Chemical fertilizer	17.58	3.79	20.08	4.44
20	None	13.76	....	14.92	....
	Average unmanured values	13.65	....	16.04	....

This table shows that there has been an average increase in the annual value of produce per acre on the unmanured land from $13.65 for the first period to $16.04 for the second; after untreated manure, from $20.57 to $26.14; from manure and raw phosphate, from $25.83 to $29.93; from manure and acid phosphate, from $25.58 to $30.99; from manure and kainit, from $23.00 to $26.31; and from manure and gypsum, from $23.55 to $27.70. (The two manures are averaged in each case.)

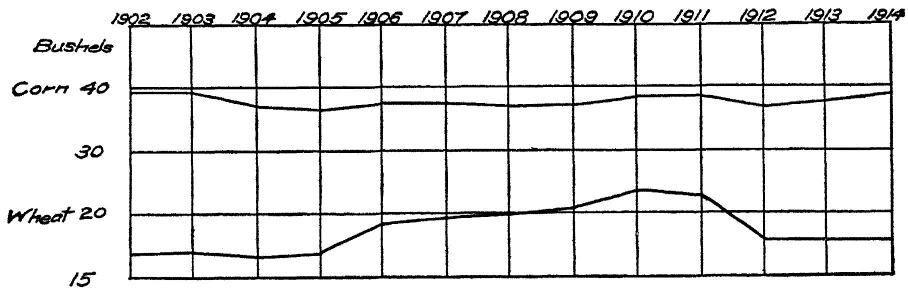

Diagram VIII.—Average yields of corn and wheat in Wayne County, shown by 6-year averages, as in Diagram VII

From these data it would appear that there has been an average net gain in the value of the annual produce per acre on the unmanured land of $2.39 for the second period over that of the first; on the land dressed with untreated manure of $5.57; with manure and raw phosphate, $4.10; with manure and acid phosphate, $5.41; with manure and kainit, $3.31, and with manure and gypsum, $4.15.

Deducting the gain on the unmanured land as representing a gain not due to the treatment, we find the net gain from untreated manure to have been $3.18; from manure and raw phosphate, $1.71; from manure and acid phosphate, $3.02; from manure and kainit, $0.92; and from manure and gypsum, $1.76. These gains represent, not the total effect of the treatment, but the cumulative effect during the second period over that realized during the first period. It appears, therefore, that, as judged by the total yields, the reinforcement of the manure, while still increasing its effectiveness, has produced a relatively smaller effect during the later than during the earlier years of the test.

Considering the results obtained by comparing the yield from each treatment with that of the untreated land joining, we fina that the average gain per acre for untreated manure has been from $7.46 to $10.25, or $2.79; for manure and raw phosphate, from $11.92 to $13.21, or $1.29; for manure and acid phosphate, from $13.11 to $16.46, or $3.35; for manure and kainit, from $10.21 to $11.65, or $1.44, and for manure and gypsum, from $9.45 to $10.98, or $1.53, the yard manure and stall manure plots being averaged in each case.

Setting these two comparisons side by side, the one made on the total yields of the land without regard to its variation in natural fertility, the other made by using the untreated check plots which adjoin every manured plot, we get the following results:

TABLE XVII.—The reinforcement of manure. Annual value per acre of gain in yield for second period over first as compared with entire yield and with adjoining checks

Treatment	Compared with:	
	Entire yield	Adjoining checks
Manure untreated	$3.18	$2.79
Manure and raw phosphate	1.71	1.29
Manure and acid phosphate	3.02	3.35
Manure and kainit	.92	1.44
Manure and gypsum	1.76	1.53

When this experiment was begun it was expected that, while the acid phosphate might produce a larger increase during the first years of the comparison, the larger amount of phosphorus given in the raw phosphate would gradually become available and eventually the manure treated with this phosphate would produce the larger crops. It will be observed that, whichever method of comparison is employed, the exact opposite of this expectation has been realized during the later years, the acid phosphate showing the greater increase in effectiveness.

Dr. C. G. Hopkins, commenting on this experiment in *The Farmer's Review* for May 13, 1916, suggests that this outcome may be due to the fact that—

> Nitrogen is almost certainly becoming a limiting element in the yield of the grain crops, so that the larger amount of phosphorus supplied in the rock phosphate cannot be utilized because of lack of nitrogen. A still further complication is due to the application of ground limestone during the later years of the experiment, thus overcoming the tendency of acid phosphate to increase the soil acidity. When nitrogen is allowed to become a limiting element the manufactured land plaster contained in the acid phosphate may exert an influence by helping to prevent loss of ammonia when mixed with manure.

It is true that the gypsum-treated manure has shown, during the later years of the test, a rate of increase in efficiency as great as that shown by the raw phosphate (although it has not produced as large a yield of crops), but if acid phosphate serves the double purpose of reinforcing the manure with phosphorus and conserving its ammonia, whereas the raw phosphate serves but the one purpose, it is an additional point of value for the acidulated phosphate.

Whether this is the chief reason for the superior efficiency of acid phosphate seems doubtful, for two reasons: In the first place, the yields of clover have been much larger during the second period than during the first, and therefore the clover has been able to furnish more nitrogen to the succeeding crops. In the second place, the yard manure has shown a relatively greater effect during the second period than during the first, as compared with the stall manure, as shown by Table XVIII.

TABLE XVIII.—Average yield and increase from manure.
Annual value per acre

Treatment	First period		Second period	
	Yield	Increase	Yield	Increase
Yard manure	$22.26	$ 9.26	$27.40	$11.60
Stall manure	24.75	11.50	29.06	13.53
Stall manure over yard manure	2.49	2.24	1.66	1.93

It will be remembered that the yard manure, as used in this experiment, is exposed to the weather during the winter months only. During the first 6 years it was weighed out of the barnyard in the spring, but since this method gave no information respecting the quantity of fresh manure required to produce a ton of yard manure the practice was changed, and a quantity of fresh manure is now divided in the early winter into 10 lots of 1,000 pounds each. These lots are treated in pairs with the reinforcing materials, and one lot of each pair is at once spread upon the field as "stall" manure, while the other is kept in a flat pile until spring, when it also is spread upon the land as "yard" manure, and both are plowed under for corn.

The yard manure is weighed when taken up in the spring and is frequently found to weigh more then than it did when first taken from the stable, depending upon the recent weather conditions, but in the general average there has been a loss of 34 pounds, or 3.4 percent of the original weight.

When the manure is analyzed, however, it is found that the losses of its fertilizing constituents have been much greater than would be indicated by its weight, as shown by Table XIX, which gives the percentage loss sustained by the differently treated manures, as ascertained by 5 years' analyses of the manures used in this test, made when first taken from the stable and after about 3 months exposure to winter weather.

TABLE XIX.—Percentage loss in manure during 3 months exposure in winter

Treatment of manure	Total weight	Organic matter	Nitrogen		Phosphorus		Potassium	
			Total	Soluble	Total	Soluble	Total	Soluble
None......... ...	5.8	35.5	35.6	59.0	22.5	22.5	51.0	51.9
Raw phosphate	4.3	26.7	33 6	67.1	4.5	10.8	32.9	30.7
Acid phosphate	5 4	38.1	31.5	68 2	17.0	38.7	38.0	38.9
Kainit...... ..	3.4	36.5	30.5	62.9	16.7	23.5	43.8	41.8
Gypsum..........	3.2	33.1	29.6	54.7	9.7	21.5	54.4	51.7

This table indicates an average loss of about one-third of the organic matter and nitrogen, nearly half of the potassium and about one-sixth of the phosphorus. Evidently water has taken the place of much of the organic matter as well as of the mineral constituents.

It has been suggested that the relatively smaller effect of raw phosphate during the later years of this experiment may have been due to the change in plan of treating the yard manure; but, in the first place, this change has involved only a very small reduction in the total weight of the yard manure, since the amount spread on each plot has averaged 966 pounds since the change as against 1,000 pounds before, and this 1,000 pounds presumably was not proportionately richer in organic matter than the 966 pounds used later. Since the organic matter has constituted less than one-fourth of the weight of the manure, it is hardly conceivable that a difference of 8 pounds per acre of organic matter could make any material difference in the effectiveness of the raw phosphate.

A mere glance at Diagrams II and III should be sufficient to show that in the general average the stall manure has been decidedly more effective than the yard manure; yet in the 255 separate comparisons between yard manure and stall manure that have been made during the 19 years over which this test has been carried, including 18 crops each of corn and wheat and 15 crops of clover (one crop of corn having been lost and the first three leguminous crops having been turned under) there have been 57 cases in which the yard manure has equalled or exceeded the stall manure in yield—19 of corn, 28 of wheat and 10 of hay. Nine of these exceptional cases occurred on Section A, 37 on B and 11 on C; but in the average of the 255 comparisons the excess in yield from stall manure over that from yard manure has been 3.87 bushels of corn, 0.95 bushel of wheat and 476 pounds of hay.

In ten cases the yield from the untreated yard manure has exceeded that from yard manure treated with raw phosphate, eight of which occurred on Section C and two on Section A. In five cases the untreated fresh manure has exceeded the fresh manure reinforced with raw phosphate, three of which occurred on Section C and two on Section A. In two cases the untreated yard manure has exceeded the yard manure reinforced with acid phosphate, both of which occurred on Section A, and in one case the untreated fresh manure has exceeded the fresh manure reinforced with acid phosphate, this also being on Section A, in the first year of the test.

Insect depredations have been one cause of these irregularities. The corn crop was seriously disturbed for several years by white grub, and in 1909 the outcome was such that the results for that year have been thrown out of the averages as being evidently misleading. The actual yields obtained are shown in Diagram IX, which gives the relative positions of the plots and the bushels harvested per acre.

The uneven work of the white grubs, without reference to treatment, but rather with reference to location, would seem to be evident from the yields of the unfertilized plots, which show that the greatest injury was done over the strip included between Plots 4 and 7, and 14 and 17.

Plot	Treatment	Yield		Treatment	Yield	Plot
11	Nothing	14.8	SECTION A	Nothing	25.9	1
12	Yard manure and gypsum	35.4		Yard manure and floats	56.5	2
13	Stall manure and gypsum	42.7		Stall manure and floats	65.6	3
14	Nothing	5.3		Nothing	7.8	4
15	Yard manure, untreated	25.8		Yard manure and acid phos.	37.3	5
16	Stall manure, untreated	43.7		Stall manure and acid phos.	36.5	6
17	Nothing	2.7		Nothing	1.0	7
18	Chemical fertilizer	28.5		Yard manure and kainit	15.0	8
19	Chemical fertilizer	28.6		Stall manure and kainit	38.6	9
20	Nothing	12.6		Nothing	17.3	10

Diagram IX.—Yield of corn in 1909 as affected by white grub

The average yields per acre on the unfertilized plots of this section, for the six crops of corn which have been grown on it, excluding that of 1909, have been as below:

Plot	Bushels	Plot	Bushels
1	32.56	11	24.20
4	23.96	14	23.30
7	21.29	17	25.34
10	23.46	20	22.06

The wheat crop passed through two attacks of Hessian fly, one culminating in 1901, when the average unfertilized yield was reduced to 4 bushels per acre, and another in 1912, when the unfertilized yield fell to 3 bushels. As the injury from the fly attacks were more uniformly distributed over the field than that from the white grub, the results for these seasons have been included in the averages, for the object of such an experiment is to ascertain what effect the treatment will have in times of adversity as well as of prosperity.

In Table XX is given the average annual increase of crop due to the manure in this experiment during the last 9 years, as found, first, by comparing each manured plot with the unmanured plots between which it lies, following the method of progressive averages in use at this Station, and second, by using the average of the four unmanured plots in each range as the basis of comparison for that range; that is, Plots 2, 3, 5, 6, 8 and 9 are compared with the average of Plots 1, 4, 7 and 10, and Plots 12, 13, 15, 16, 18 and 19 are compared with the average of Plots 11, 14, 17 and 20.

The composition of the manures used in this experiment was determined for 5 years in the chemical laboratories of this Station.

From these analyses Table XXI has been compiled, showing the average amount of nitrogen, phosphorus and potassium found in the manures as first taken from the stable (stall manure) and after 3 months exposure in the open yard (yard manure).

TABLE XX.—Experiments in the reinforcement of manure. Increase due to manures as shown by different methods of comparison

Plot	Corn				Wheat				Hay	
	Progressive		Range		Progressive		Range		Progressive	Range
	Grain	Stover	Grain	Stover	Grain	Straw	Grain	Straw		
	Bu.	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*	*Bu.*	*Lb.*	*Lb.*	*Lb.*
2	31.21	1,324	35.73	1,539	10.91	1,108	12.12	1,171	1,650	1,946
3	37.87	1,596	38.65	1,660	12.92	1,357	13.56	1,384	2,139	2,157
5	39.02	1,548	35.44	1,430	15.29	1,692	15.15	1,677	2,210	1,972
6	43.14	1,702	38.92	1,555	15.63	1,756	15.27	1,735	2,605	2,389
8	28.81	1,381	25.43	1,229	10.00	1,025	9.18	986	1,242	1,072
9	33.31	1,531	31.41	1,404	11.34	1,243	10.30	1,191	1,822	1,677
12	29.08	1,262	30.32	1,331	10.44	1,110	11.97	1,241	959	1,167
13	32.25	1,351	30.00	1,310	11.51	1,220	12.08	1,219	1,336	1,279
15	23.36	827	20.71	777	10.45	1,062	10.10	971	1,074	874
16	27.58	1,000	28.03	1,051	11.37	1,232	11.06	1,185	1,618	1,539
18	15.74	520	17.25	562	7.14	632	6.35	577	329	293
19	12.15	426	11.64	357	4.43	479	3.13	393	455	342

TABLE XXI.—Experiments in the reinforcement of manure. Composition of manure in pounds per ton

Treatment	Stall manure			Yard manure		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
Raw phosphate	13.12	5.59	10.86	8.71	5.34	7.28
Acid phosphate	13.18	4.80	10.60	9.02	3.32	6.57
Kainit	13.01	2.34	14.05	9.04	1.95	7.89
Gypsum	13.56	2.26	10.63	9.54	2.04	4.85
Untreated	13.53	2.36	11.19	8.71	1.83	5.48
Average*	13.28	2.32	10.82	9.00	1.94	6.04

*Excluding the phosphorus from the phosphated manures and the potassium from those treated with kainit.

Our investigations have shown that fresh manure may suffer a considerable loss of nitrogen in drying. When dried at a temperature of 60° C. (140° F.) for 7 days there was a loss of 30 percent of the nitrogen from cattle manure and 24 percent from horse manure.[1] Later unpublished experiments have shown that manure exposed in the open air in the fall may lose 20 percent or more of its

[1]Ohio Agr. Exp. Sta. Bul. 246, p. 753.

nitrogen in 60 days. It is assumed that the rate of loss would be less in winter weather, but the outcome of the field experiments now under consideration shows that there has apparently been a considerable loss of nitrogen from the stall manure during its 3 months' exposure, and therefore the amount actually placed at the disposal of the crop is estimated at 80 percent of the total amount contained as it came from the stable, in Table XXII, which shows the amount of nitrogen given in the manure, the amount recovered in the increase of crop, and the percentage which this increase in nitrogen is of that contained in the manure, using both methods of comparison.

TABLE XXII.—Experiments in the reinforcement of manure. Nitrogen supplied in manure and recovered in increase of crop. 9-year average

Plot	Manure and treatment	Supplied per acre	Recovered in increase per acre*			
			Progressive comparisons		Range comparisons	
	Yard manure with:	*Pounds*	*Pounds*	*Percent*	*Pounds*	*Percent*
2	Raw phosphate	70	98	140	113	161
5	Acid phosphate	72	129	179	118	164
8	Kainit	72	86	120	76	106
12	Gypsum	76	80	105	89	117
15	Untreated	70	72	103	64	91
	Stall manure with:					
3	Raw phosphate	85	122	143	124	146
6	Acid phosphate	85	143	168	132	155
9	Kainit	85	107	126	99	116
10	Gypsum	85	94	110	91	107
16	Untreated	85	92	108	91	107

*The following factors, derived from analyses at this Station, are used in this and following tables:

	Nitrogen	Phosphorus	Potassium
Ear corn, pounds per bushel	1.05	0.137	0.28
Wheat, pounds per bushel	1.18	.209	.213
Corn stover, pounds per 100	.81	.067	.78
Wheat straw, pounds per 100	.53	.091	.83
Clover hay, pounds per 100	2.17	.183	1.12

Table XXII shows that the amount of nitrogen recovered in the increase of crop has been greater than that carried in the manure.

Some combined nitrogen is carried to the soil annually in the rainfall, but this would not affect the present comparison, as it would affect manured and unmanured land alike. The larger yields of clover grown on the manured land would, however, increase the nitrogen supply for the following crop by the nitrogen left in its roots and stubble.

The nitrogen content of the residues of leguminous crops has been studied by Penny, of the Delaware Experiment Station,[1] and others, whose work is summarized by Dr. C. G. Hopkins,[2] who concludes that one-third of the total nitrogen of the clover plant may be found in the roots and stubble, or, in other words, that these residues will contain half as much nitrogen as the tops. To add this amount to the nitrogen supply would give, for the land receiving phosphated manure, the results shown in Table XXIII.

TABLE XXIII.—Experiments in the reinforcement of manure. Total nitrogen supply and percentage recovered in increase of crop

Plot	Manure and treatment	Total supply		Total recovery	
		Progressive comparison	Range comparison	Progressive comparison	Range comparison
	Yard manure with:	*Pounds*	*Pounds*	*Percent*	*Percent*
2	Raw phosphate	88	91	111	124
5	Acid phosphate	96	93	134	127
	Stall manure with:				
3	Raw phosphate	108	108	113	115
6	Acid phosphate	113	111	132	122

Table XXIII shows that, after the clover residues are credited with a considerable amount of nitrogen, there is still a greater amount in the increase harvested from the phosphated plots than can be accounted for in the annual supply, thus suggesting either that the nitrogen reserves of the soil are being drawn upon or that the clover bacteria and possibly also those which directly combine atmospheric nitrogen with the phosphorus, potassium and other mineral elements in the soil, are finding in the phosphated manure used in these experiments conditions especially favorable for their work. This question is being studied by means of chemical determinations of the amount of soil nitrogen, made in 1907, at the beginning of the 9-year period under review, and again in the spring of 1916. The results are shown in Table XXIV, for the north half of each section. The table indicates a small loss of nitrogen on the unfertilized land and after manure reinforced with acid phosphate, with a small gain of nitrogen after the raw phosphate-treated and kainit-treated manure.

[1]Del. Exp. Sta. Bul. 67.
[2]*Soil Fertility and Permanent Agriculture*, p. 218.

TABLE XXIV.—Experiments in the reinforcement of manure. Pounds of nitrogen per acre in the upper 7 inches. Comparison of soils in 1907 and 1916. Section A

Plot	Manure and treatment	Pounds of nitrogen per acre		
		1907	1916	Increase or decrease
1	No manure	1,840	1,790	— 50
4	" "	1,810	1,650	—160
7	" "	1,860	1,760	—100
10	" "	1,950	1,684	—266
	Yard manure with:			
2	Raw phosphate	1,840	1,890	+ 50
5	Acid phosphate	2,110	2,020	— 90
8	Kainit	1,880	2,020	+140
	Stall manure with:			
3	Raw phosphate	2,060	2,090	+ 30
6	Acid phosphate	2,130	1,984	—146
9	Kainit	2,020	2,030	+ 10

The estimated balance between the supply and recovery of potassium and phosphorus is given in Tables XXV and XXVI. Table XXV shows that where yard manure has been reinforced with phosphorus more potassium has been found in the increase produced than was given in the manure, potassium following nitrogen in this respect.

TABLE XXV.—Experiments in the reinforcement of manure. Potassium supplied and recovered in increase of crop. 9-year average.

Plot	Manure and treatment	Supplied	Recovered in increase			
			Progressive comparison		Range comparison	
	Yard manure with:	*Pounds*	*Pounds*	*Percent*	*Pounds*	*Percent*
2	Raw phosphate	48	49	100	56	117
5	Acid phosphate	48	65	135	60	125
8	Kainit	70	43	60	39	56
10	Gypsum	48	40	83	45	94
15	Untreated	48	36	75	32	67
	Stall manure with:					
3	Raw phosphate	86	61	71	62	72
6	Acid phosphate	86	72	84	67	78
9	Kainit	118	54	46	51	43
13	Gypsum	86	47	55	46	53
16	Untreated	86	46	53	43	50

The gypsum-treated yard manure shows a recovery of 83 to 94 percent of the potassium, while from the untreated yard manure the recovery has been but two-thirds to three-fourths of that given in the manure.

On the land dressed with stall manure the percentage recovery of potassium has been considerably less than on that receiving yard manure, although the total amount is greater.

TABLE XXVI.—Experiments in the reinforcement of manure. Phosphorus supplied and recovered in increase of crop. 9-year average

Plot	Manure and treatment	Supplied	Recovered in increase			
			Progressive comparison		Range comparison	
		Pounds	*Pounds*	*Percent*	*Pounds*	*Percent*
	Yard manure with:					
2	Raw phosphate	53.0	12.3	23	13.1	25
5	Acid phosphate	34.3	15.2	44	14.1	41
8	Kainit	14.6	10.2	70	9.1	64
12	Gypsum	14.6	9.8	67	10.8	74
15	Untreated	14.6	9.7	66	7.9	54
	Stall manure with:					
3	Raw phosphate	57.3	14.1	25	14.6	26
6	Acid phosphate	38.6	16.7	43	15.5	40
9	Kainit	18.9	12.4	65	11.5	61
13	Gypsum	18.9	11.3	60	11.8	62
16	Untreated	18.9	10.8	57	10.8	58

In the case of phosphorus these tables indicate that the recovery from untreated manure has not exceeded two-thirds of the amount found in the manure. The treatment of manure with gypsum or kainit has slightly increased the recovery of phosphorus, but the highest recovery shown by either method of calculation is three-fourths of the phosphorus from the gypsum-treated manure, as shown by the range comparisons. It would appear, therefore, that a considerable proportion of the phosphorus carried in manure must be in an unavailable form.

THE STRONGSVILLE EXPERIMENTS

One of the most interesting of the Ohio Station's wheatfields is on the Strongsville test-farm, where wheat has been grown since 1897 in the same 5-year rotation of corn, oats, wheat, clover and timothy as that at the main station. For the first 10 years the unfertilized wheat in this test averaged less than 6 bushels per acre, as against a little under 9 bushels for the duplicate test at the main station. Since 1905 the corn crop in the Strongsville test has received an annual dressing of 2 tons per acre of ground limestone on half the land and 1 ton of raw phosphate rock on the other half, these dressings being applied to fertilized and unfertilized land alike.

The plan and estimated cost of fertilizing certain parts of this experiment are shown in Table XXVII.

TABLE XXVII.—Plan of fertilizing in 5-year rotations

Plot	Fertilizer	Pounds per acre				Estimated cost	
		On corn	On oats	On wheat	Total		
2	Acid phosphate	80	80	160	320		$ 2.24
8	Acid phosphate	80	80	160	320	$ 2.24	8.74
	Muriate of potash	80	80	100	260	6.50	
11	Acid phosphate	80	80	160	320	2.24	23.14
	Muriate of potash	80	80	100	260	6.50	
	Nitrate of soda	160	160	160	480	14.40	
17	Acid phosphate	160	160	160	480	3.36	17.06
	Muriate of potash	80	80	100	260	6.50	
	Nitrate of soda	80	80	80	240	7.20	
18	Yard manure	16,000	....	16,000	....	....	

It was not practicable in this test to leave any of the land without either limestone or floats, but we can form some estimate of the effect of the treatment by comparing the yields for the period since this treatment was begun with those of the previous 10 years. This is done in Table XXVIII, which shows the average yields of the unfertilized land and of that receiving a few of the fertilizer and manure treatments, for the first two rotations, or 10 years, and for the subsequent period, including the crops of 1915.

In considering the first period, it will be seen that acid phosphate produced a marked increase in all the crops of the rotation, raising the total value of the five crops from $46.31 to $63.68, or to $61.44 after the cost of the fertilizer was deducted. When muriate of potash was added to the acid phosphate there was a further increase in yield, but not enough to pay the largely increased cost of the fertilizer. The addition of nitrate of soda caused a further increase in yield, but again the added cost of the fertilizer reduced the net gain.

Table XXVIII shows that the increase for acid phosphate for the five crops of the rotation was $17.37 during the first 10 years and $19.76 on the limed land during the second period.

The combined yield for lime and acid phosphate during the second period was $33.64 greater than the unfertilized yield during the first period, while the yield for raw phosphate was $31.69 greater. The cost of the combined dressing of acid phosphate and lime is computed at $8.24 per acre for the five crops, and that of raw phosphate at $8.50, so that the net return from the acid phosphate and lime has been $71.71, and that from the raw phosphate, $69.50.

TABLE XXVIII.—Experiments with limestone and raw phosphate at Strongsville

Plot	Fertilizers	Average yield per acre					Value of five crops	Cost of treatment	Net value
		Corn Bu.	Oats Bu.	Wheat Bu.	Clover T.	Timothy T.			
	First 10 years. No lime nor raw phosphate								
	None	23.3	34.8	5.6	0.68	0.83	$46.31	....	$46.31
2	Acid phosphate	28.7	43.9	11.5	1.04	1.02	63.68	$ 2.24	61.44
8	Acid phosphate; Muriate of potash	31.3	46.4	13.7	1.02	1.03	68.40	8.74	59.66
11	Acid phosphate; Muriate of potash; Nitrate of soda	34.8	53.1	16.4	1.11	1.21	76.93	23.14	53.79
9	Muriate of potash; Nitrate of soda	24.5	38.7	7.6	.76	.91	52.03	20.90	31.13
17	Acid phosphate; Muriate of potash; Nitrate of soda	34.9	51.6	14.6	1.08	1.01	73.69	17.06	56.63
18	Yard manure	36.0	42.7	14.2	1.05	1.07	70.52	8.00	62.52
	Second period: Limed land								
	None	27.5	31.6	9.5	1.12	1.31	60.19	6.00	54.19
2	Acid phosphate	33.7	39.0	16.1	1.71	1.43	79.95	8.24	71.71
8	Acid phosphate; Muriate of potash	39.9	41.8	19.0	1.50	1.47	85.37	14.74	70.63
11	Acid phosphate; Muriate of potash; Nitrate of soda	43.2	46.3	22.0	1.68	1.65	95.42	29.14	66.37
9	Muriate of potash; Nitrate of soda	30.0	35.5	12.2	1.28	1.26	66.80	26.90	39.90
17	Acid phosphate; Muriate of potash; Nitrate of soda	45.0	47.5	22.8	1.85	1.84	101.20	23.06	78.14
18	Yard manure	46.5	44.3	21.1	1.99	1.90	100.97	14.00	86.97
	Second period: Raw phosphate-treated land								
	None	29.9	39.1	12.4	1.71	1.79	78.00	8.50	69.50
2	Acid phosphate	29.3	42.6	15.7	1.70	1.78	82.19	10.74	71.25
8	Acid phosphate; Muriate of potash	45.4	48.0	17.9	2.11	2.15	102.40	17.24	85.16
11	Acid phosphate; Muriate of potash; Nitrate of soda	44.4	52.7	23.7	2.18	2.00	108.78	31.64	77.14
9	Muriate of potash; Nitrate of soda	43.7	49.4	16.7	2.05	1.74	96.21	29.40	67.81
17	Acid phosphate; Muriate of potash; Nitrate of soda	44.8	47.0	20.3	2.21	1.96	103.20	25.56	77.64
18	Yard manure	46.3	44.1	19.5	2.41	2.15	105.89	16.50	89.39

When acid phosphate, costing $2.24, has been added to the raw phosphate there has been a further increase of $4.19 in the value of the crops, thus showing that the demand of this soil for phosphorus has not been satisfied by 1 ton of raw phosphate, applied every 5 years. The net value from the combination of acid phosphate and raw phosphate has been $71.25, or nearly the same as that from acid phosphate and limestone.

When muriate of potash has been added to the fertilizer, at a cost of $6.50 for the five crops, there has been an increase in the value of the crops of $4.72 during the first period and of $5.42 on the limed land and $20.21 on the raw phosphate-treated land during the second period, over the value of the crops receiving acid phosphate and limestone or acid phosphate and raw phosphate.

Nitrate of soda, costing $14.40 for each 5-year period, has caused a further increase in yield during the first period of $8.53, and during the second of $10.05 on the limed land and of $6.38 on the raw phosphate-treated land. The total produce, however, has been $13.36 greater, and the net value, $10.83 greater on the raw phosphate-treated land than on the limed land. The abundant supply of phosphorus has apparently enabled the crops to secure a much larger supply of nitrogen, independently of that furnished in the fertilizer.

Plot 9 receives the same quantity of muriate of potash and nitrate of soda as Plot 11, but no acid phosphate. On the limed land the yield of Plot 11 is $95.42, and on the land dressed with raw phosphate the yield of Plot 9 is $96.21—the total effect of 1 ton of raw phosphate again being nearly the same as the combined effect of 2 tons of raw limestone and 320 pounds of acid phosphate.

Plot 17 receives the same quantity of muriate of potash as Plot 11, with half as much nitrate of soda and 50 percent more acid phosphate. On the limed land, Plot 17 exceeds Plot 11 in yield, but on the unlimed land and the raw phosphate-treated land the yield is greater on Plot 11.

On the limed land phosphorus is more effective than either nitrogen or potassium in producing increase of crop, but when phosphorus is supplied in abundance then both nitrogen and potassium are able to perform their full function.

As between the two carriers of phosphorus, the large yield on Plot 17 on the limed land indicates a high efficiency for acid phosphate. In this case the net results from the application of a ton of raw phosphate and a complete fertilizer containing 480 pounds of acid phosphate have been nearly the same as from 2 tons of limestone and the same fertilizer.

The raw phosphate with which this experiment was begun was donated by Robin Jones, of Nashville, Tennessee, with the statement that it contained about 3 percent available phosphoric acid in a total of 27 percent. The outcome of the experiment indicates that its efficiency has been practically measured by the 3 percent of available phosphoric acid.

A DIRECT COMPARISON OF ACID PHOSPHATE AND RAW PHOSPHATE

In 1905 the Ohio Experiment Station began another test, in which acid phosphate and raw phosphate rock are used as direct applications to the land, unmixed with manure, in a 3-year rotation of corn, oats and clover, each crop being grown every season. The plan of this test and the results to 1913 are given in Circular 144. In Table XXIX are given the average results for the 11 years, 1905-1915, for the part of the land devoted to the phosphate comparison. In this experiment the fertilizing materials are all applied to the corn crop. The land used had been under rotative cropping, with occasional dressings of manure, for some years before the experiment was begun, and the unfertilized yields are therefore larger than in the tests previously considered.

The financial outcome of this comparison is shown in Table XXX, the same valuations being used as those previously employed.

This experiment has been conducted on a soil much better supplied with organic matter than the average and in which this supply is maintained by the frequent growing of clover. The increase produced has paid a large profit on the cost of the raw phosphate, but the acid phosphate has produced an increase so much greater as to render the use of the raw phosphate relatively unprofitable. The difference in the cost of treatment has been only 22 cents per acre, while the difference in net gain has in every case been greater than the entire cost of the acid phosphate.

TABLE XXIX.—Comparison of raw phosphate and acid phosphate used in the absence of manure.
11-year average yield and increase per acre, 1905-1915

Plot	Treatment	Corn		Oats		Hay
		Grain	Stover	Grain	Straw	
	Yield per acre					
		Bu.	*Lb.*	*Bu.*	*Lb.*	*Lb.*
16	None	47.73	2,586	43.90	1,724	3,358
17	Acid phosphate, 320 lb.; muriate potash, 40 lb.; lime, 1,000 lb	70.00	3,494	50.26	1,984	4,676
18	Raw phosphate, 320 lb,, muriate potash, 40 lb.; lime, 1,000 lb	65.44	3,330	47.86	1,877	4,454
19	None	49.36	2,605	44.07	1,801	3,528
20	Acid phosphate, 320 lb	58.82	2,935	45.39	1,816	3,823
21	Acid phosphate, 320 lbs.; muriate potash, 40 lbs	64.53	3,188	47.80	1,911	4,010
22	None	48.37	2,523	43.27	1,699	3,573
23	Raw phosphate, 320 lb.	52.82	2,657	44.12	1,737	3,588
24	Raw phosphate, 320 lb. muriate potash, 40 lb	55.95	2 905	43.45	1,701	3,467
25	None	45.03	2,430	43.26	1,630	3,284
	Average unfertilized yield	47.62	2,536	43.62	1,713	3,436
	Increase per acre					
17	Acid phosphate, 320 lb.; muriate potash, 40 lb.; lime, 1,000 lb.	21.73	901	6.30	234	1,162
18	Raw phosphate, 320 lb.; muriate potash, 40 lb.; lime, 1,000 lb	16.62	732	3.85	102	982
20	Acid phosphate, 320 lb	9.78	358	1.59	49	280
21	Acid phosphate, 320 lb.; muriate potash, 40 lb	15.83	638	3.27	177	451
23	Raw phosphate, 320 lb.	5 56	165	1.53	61	112
24	Raw phosphate, 320 lb.; muriate potash, 40 lb	9.80	444	1.51	48	87

TABLE XXX.—Summary of Table XXVIII. Annual cost of treatment, value of increase and net gain per acre

Treatment	Cost of treatment*	Value of increase	Net gain
Acid phosphate alone	$0.75	$2.44	$1.69
Raw phosphate alone	.53	1.37	.84
Acid phosphate and muriate of potash	1.08	4.08	3.00
Raw phosphate and muriate of potash	.86	2.14	1.28
Acid phosphate, muriate of potash, lime	2.08	6.70	4.62
Raw phosphate, muriate of potash, lime	1.86	5.16	3.30

*As computed on p. 247, with muriate of potash at 2½ cents per pound and lime at $C per ton.

CONCLUSIONS

In the foregoing pages is presented a brief review of the principal experiments thus far reported in the comparison of finely ground, raw phosphate rock with acid phosphate, together with a more extended report of similar comparisons made by this Station.

These experiments show conclusively that raw phosphate rock may be used with profit on land that is materially deficient in available phosphorus, but as a rule acid phosphate has proved to be not only a more effective but also a more economical carrier of phosphorus to crops under conditions which render the freight charges a relatively large part of the cost of the fertilizer.

Where a different outcome has resulted it is usually found that one or both of the phosphate carriers have been used in such large quantity as to furnish more available phosphorus than the crops were able to utilize, thus making a comparative measurement of the effect of the two carriers impossible.

In conclusion, we desire to express our obligation to Dr. C. G. Hopkins, of the Illinois Experiment Station, who has carefully studied the Ohio experiments herein reported during their entire progress, and whose constructive criticism has been most helpful in their interpretation.